

CHAPTER 3 — COLLISION AVOIDANCE

RELATIVE MOTION

In the Universe there is no such condition as absolute rest or absolute motion. An object is only at rest or in motion relative to some reference. A mountain on the earth may be at rest relative to the earth, but it is in motion relative to the sun. Although all motion is relative, as used here *actual* or *true motion* is movement with respect to the earth; *relative motion* is motion with respect to an arbitrarily selected object, which may or may not have actual or true motion.

The actual or true motion of an object usually is defined in terms of its direction and rate of movement relative to the earth. If the object is a ship, this motion is defined in terms of the true course and speed. The motion of an object also may be defined in terms of its direction and rate of movement relative to another object also in motion. The relative motion of a ship, or the motion of one ship relative to the motion of another ship, is defined in terms of the *Direction of Relative Movement (DRM)* and the *Speed of Relative Movement (SRM)*. Each form of motion may be depicted by a velocity vector, a line segment representing direction and rate of movement. Before further discussion of *velocity vectors* and their application, a situation involving relative motion between two ships will be examined.

In figure 3.1, ship A, at geographic position A1, on true course 000° at 15 knots initially observes ship B on the PPI bearing 180° at 4 miles. The bearing and distance to ship B changes as ship A proceeds from geographic position A1 to A3. The changes in the positions of ship B relative to ship A are illustrated in the successive PPI presentations corresponding to the geographic position of ships A and B. Likewise ship B, at geographic position B1, on true course 026° at 22 knots initially observes ship A on the PPI bearing 000° at 4 miles. The bearing and distance to ship A changes as

ship B proceeds from geographic position B1 to B3. The changes in the positions of ship A relative to ship B are illustrated in the successive PPI presentations corresponding to the geographic positions of ships A and B.

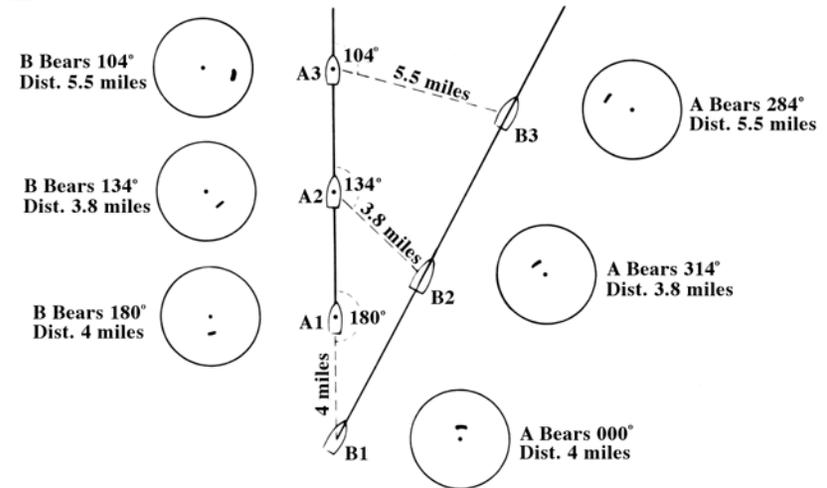


Figure 3.1 - Relative motion between two ships.

If the radar observer aboard ship A plots the successive positions of ship B relative to his position fixed at the center of the PPI, he will obtain a plot called the RELATIVE PLOT or RELATIVE MOTION PLOT as illustrated in figure 3.2.

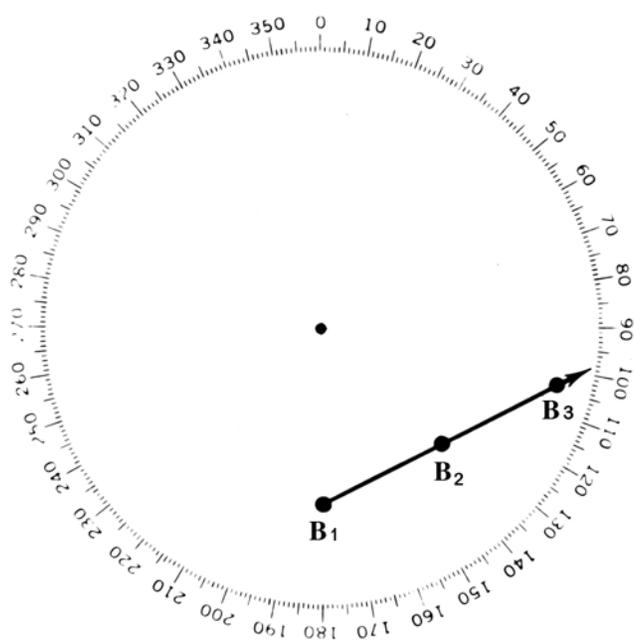


Figure 3.2 - Motion of ship B relative to ship A.

If the radar observer aboard ship B plots the successive positions of ship A relative to his position fixed at the center of the PPI, he will obtain a relative plot illustrated in figure 3.3. The radar observer aboard ship A will determine that the Direction of Relative Movement (DRM) of ship B is 064° whereas the radar observer aboard ship B will determine that the DRM of ship A is 244°.

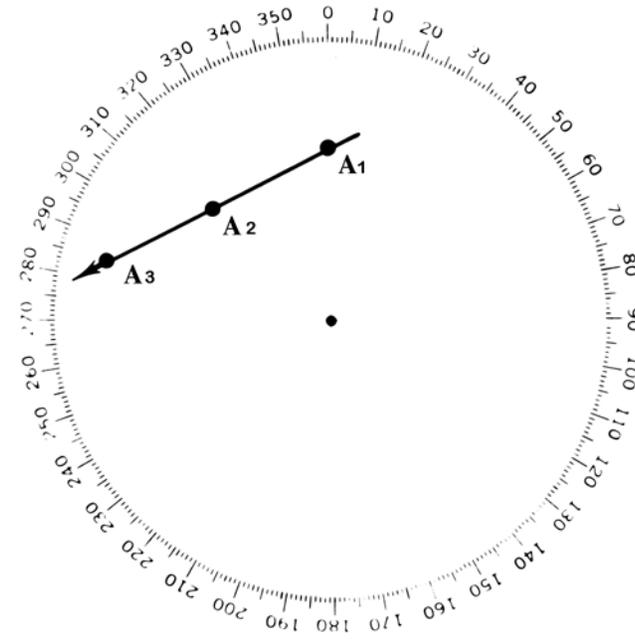


Figure 3.3 - Motion of ship A relative to ship B.

Of primary significance at this point is the fact that the motion depicted by the relative plot on each PPI is not representative of the true motion or true course and speed of the other ship. Figure 3.4 illustrates the actual heading of ship B superimposed upon the relative plot obtained by ship A. *Relative motion displays do not indicate the aspects of ship targets.* For either radar observer to determine the true course and speed of the other ship, additional graphical constructions employing relative and true vectors are required.

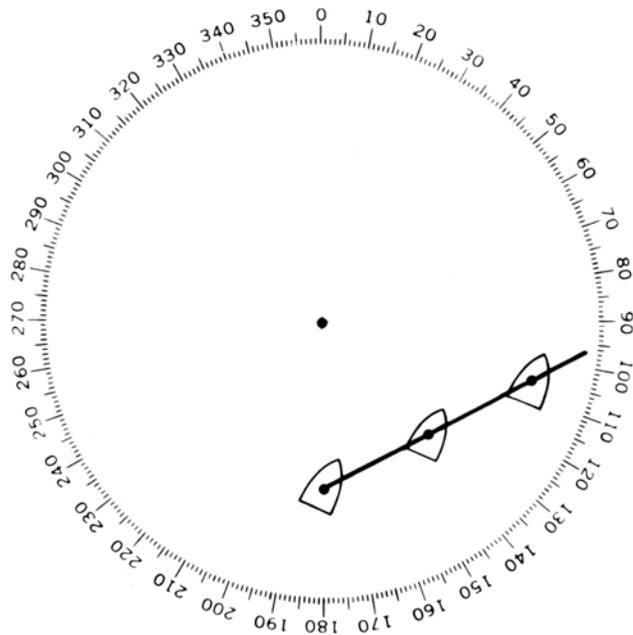


Figure 3.4 - The actual heading of ship B.

Figure 3.5 illustrates the *timed* movements of two ships, R and M, with respect to the earth. This plot, similar to the plot made in ordinary chart navigation work, is called a geographical (navigational) plot. Ship R proceeding on course 045°, at a constant speed passes through successive positions $R_1, R_2, R_3, R_4...$ equally spaced at equal time intervals. Therefore, the line segments connecting successive positions represent direction and rate of movement with respect to the earth. Thus they are true velocity vectors. Likewise, for ship M on course 325° the line segments connecting the equally spaced plots for equal time intervals represent true velocity vectors of ship M. Although the movement of R relative to M or M relative

to R may be obtained by additional graphical construction or by visualizing the changes in bearings and distances between plots coordinated in time, the geographical plot does not provide a *direct* presentation of the relative movement.

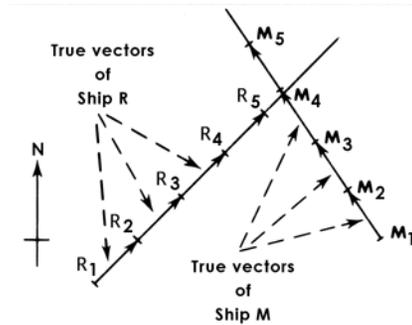


Figure 3.5 - True velocity vectors.

Figure 3.6 illustrates a modification of figure 3.5 in which the true bearing lines and ranges of other ship M from own ship R are shown at equal time intervals. On plotting these ranges and bearings from a fixed point R, the movement of M relative to own ship R is directly illustrated. The lines between the equally spaced plots at equal time intervals provide direction and rate of movement of M relative to R and thus are relative velocity vectors.

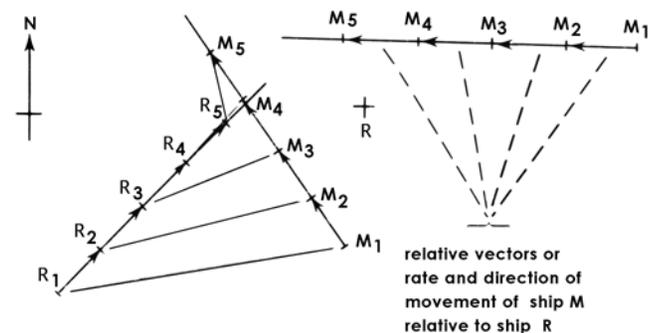


Figure 3.6 - Relative velocity vectors.

The true velocity vector depicting own ship's true motion is called *own ship's true (course-speed) vector*; the true velocity vector depicting the other ship's true motion is called *other ship's true (course-speed) vector*; the relative velocity vector depicting the *relative motion* between own ship and the other ship is called the *relative (DRM-SRM) vector*.

In the foregoing discussion and illustration of true and relative velocity vectors, the magnitudes of each vector were determined by the time interval between successive plots.

Actually any convenient time interval can be used as long as it is the same for each vector. Thus with plots equally spaced in time, own ship's true (course-speed) vector magnitude may be taken as the line segment between R_1 and R_3 , R_1 and R_4 , R_2 and R_4 , etc., as long as the magnitudes of the other two vectors are determined by the same time intervals.

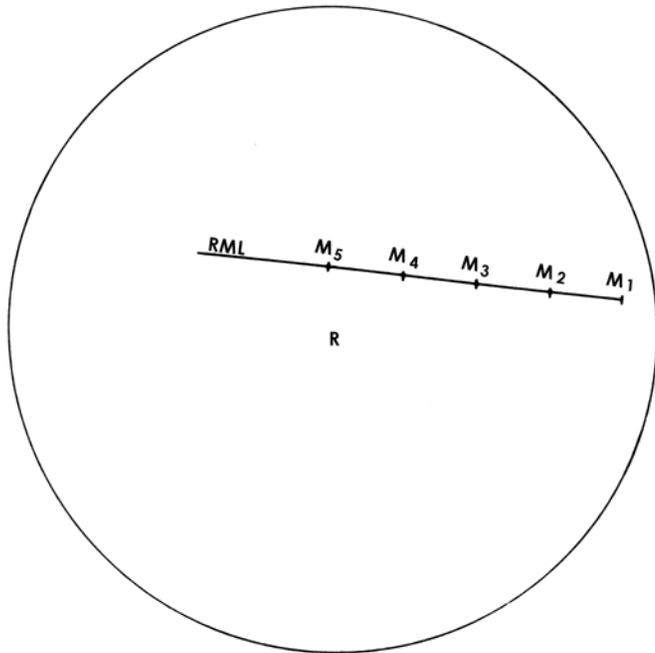


Figure 3.7 - Relative Plot.

A plot of the successive positions of other ship M in the same situation on a relative motion display on the PPI of the radar set aboard own ship R would appear as in figure 3.7. With a Relative Movement Line (RML) drawn through the plot, the individual segments of the plot corresponding to relative distances traveled per elapsed time are relative (DRM-SRM) vectors,

although the arrowheads are not shown. The plot, called the **RELATIVE PLOT** or **RELATIVE MOTION PLOT**, is the plot of the true bearings and distances of ship M from own ship R. If the plots were not timed, vector magnitude would not be indicated. In such cases the relative plot would be related to the (DRM-SRM) vector in direction only.

Figure 3.8 illustrates the same situation as figure 3.7 plotted on a Maneuvering Board. The center of the Maneuvering Board corresponds to the center of the PPI. As with the PPI plot, all ranges and true bearings are plotted from a fixed point at the center, point R.

Figure 3.8 illustrates that the relative plot provides an almost direct indication of the **CLOSEST POINT OF APPROACH (CPA)**. The CPA is the true bearing and distance of the closest approach of one ship to another.

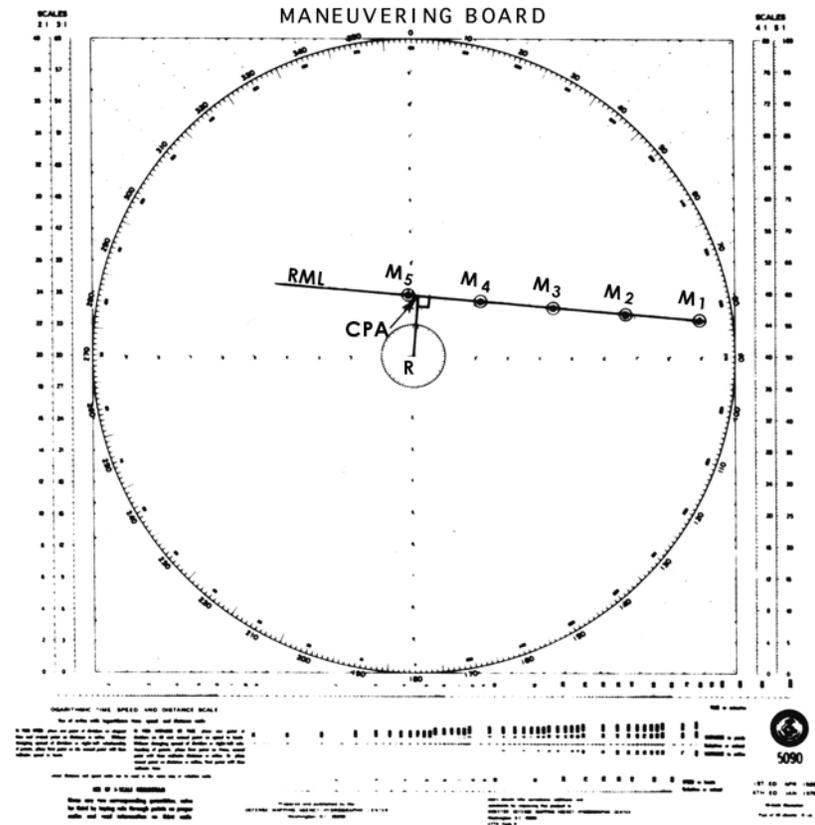


Figure 3.8 - Relative Plot on the Maneuvering Board.

THE VECTOR TRIANGLE

In the foregoing discussion, the relative motion of other ship M with respect to own ship R was developed graphically from the true motions of ship M and ship R. The usual problem is to determine the true motion (true course and speed) of the other ship M, knowing own ship's true motion (true course and speed) and, through plotting, determining the motion of ship M relative to own ship R.

The vector triangle is a graphical means of adding or subtracting two velocity vectors to obtain a resultant velocity vector. To determine the true (course-speed) vector of other ship M, the true (course-speed) vector of own ship R is added to the relative (DRM-SRM) vector derived from the relative plot, or the timed motion of other ship M relative to own ship R.

In the addition of vectors, the vectors are laid end to end, taking care that each vector maintains its *direction* and *magnitude*, the two essential elements of a vector. Just as there is no difference whether 5 is added to 3 or 3 is added to 5, there is no difference in the resultant vector whether the relative (DRM-SRM) vector is laid at the end of own ship's true (course-speed) vector or own ship's true (course-speed) vector is laid at the end of the relative (DRM-SRM) vector. Because of the notations used in this manual, the relative (DRM-SRM) vector is laid at the end of own ship's true (course-speed) vector, unless otherwise specified.

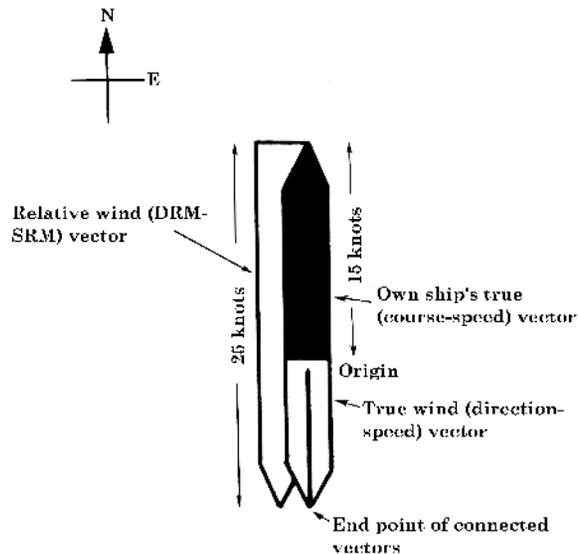


Figure 3.9 - Relative and true wind vectors.

The resultant vector, the true (course-speed) vector of other ship M, is found by drawing a vector from the origin of the two connected vectors to their end point. Unless the two vectors added have the same or opposite directions, a triangle called the vector triangle is formed on drawing the resultant vector.

Insight into the validity of this procedure may be obtained through the mariner's experience with the effect of a ship's motion on the wind.

If a ship is steaming due north at 15 knots while the true wind is 10 knots *from* due north, the mariner experiences a relative wind of 25 knots *from* due north. Assuming that the mariner does not know the true wind, it may be found by laying own ship's true (course-speed) vector and the relative wind (DRM-SRM) vector end to end as in figure 3.9.

In figure 3.9, own ship's true (course-speed) vector is laid down in a due north direction, using a vector magnitude scaled for 15 knots. At the end of the latter vector, the relative wind (DRM-SRM) vector is laid down in a due south direction, using a vector magnitude scaled for 25 knots. On drawing the resultant vector from the origin of the two connected vectors to their end point, a true wind vector of 10 knots in a due south direction is found.

If own ship maintains a due north course at 15 knots as the wind direction shifts, the relative wind (DRM-SRM) vector changes. In this case a vector triangle is formed on adding the relative wind (DRM-SRM) vector to own ship's true (course-speed) vector (see figure 3.10).

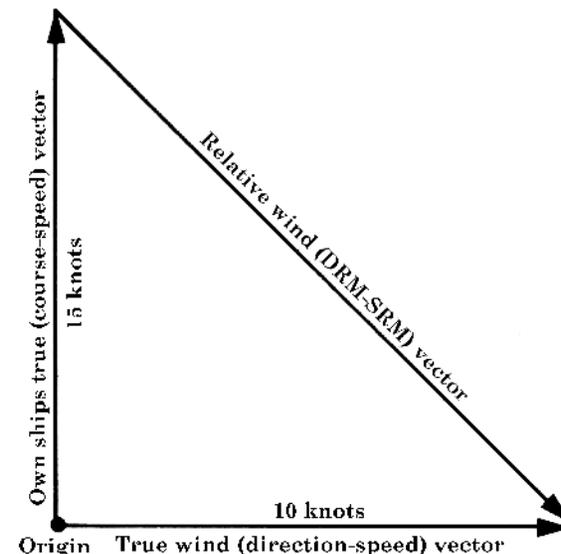


Figure 3.10 - Wind vector triangle.

Returning now to the problem of relative motion between ships and using the same situation as in figure 3.7, a *timed* plot of the motion of other ship M relative to own ship R is made on the PPI as illustrated in figure 3.11.

Assuming that the true (course-speed) vector of other ship M is unknown, it may be determined by adding the relative (DRM-SRM) vector to own ship's true (course-speed) vector.

The vectors are laid end to end, while maintaining their respective directions and magnitudes. The resultant vector, the true (course-speed) vector of other ship, is found by drawing a vector from the origin of the two connected (added) vectors to their end point.

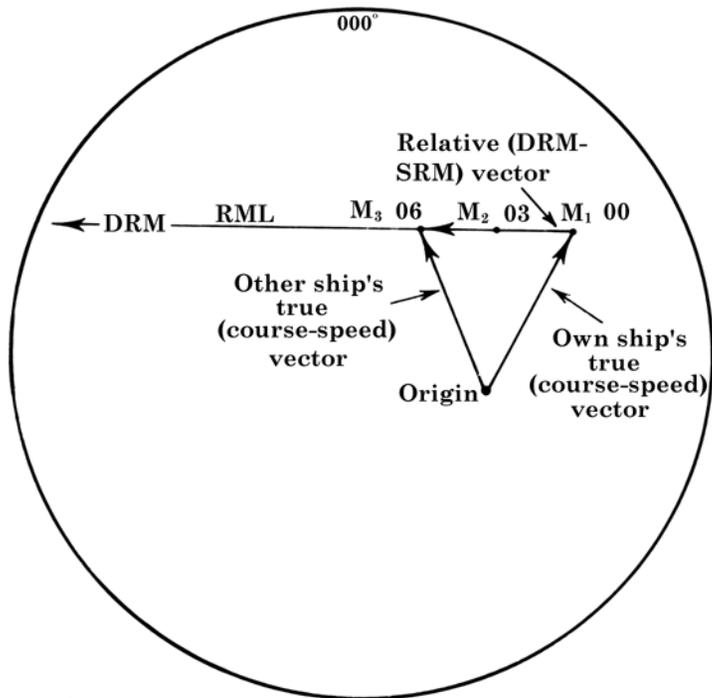


Figure 3.11 - Vector triangle on PPI.

VECTOR EQUATIONS

Where:

em is other ship's true (course-speed) vector.

er is own ship's true (course-speed) vector.

rm is relative (DRM-SRM) vector.

$$em = er + rm$$

$$er = em - rm$$

$$rm = em - er$$

(See figure 3.12)

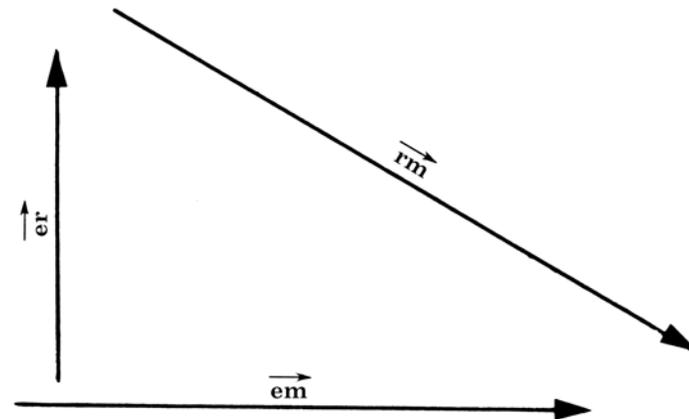


Figure 3.12 - True and relative vectors.

To determine vector em from vectors er and rm , vectors er and rm are added by laying them end to end and drawing a resultant vector, em , from the origin of the two connected vectors to their end point (see figure 3.13).

To determine vector er from vectors em and rm , vector rm is subtracted from vector em by laying vector rm , with its direction reversed, at the end of vector em and drawing a resultant vector, er , from the origin of the two connected vectors to their end point (see figure 3.14).

To determine vector rm from vectors em and er , vector er is subtracted from vector em by laying vector er , with its direction reversed, at the end of vector em and drawing a resultant vector from the origin of the two connected vectors to their end point (see figure 3.15).

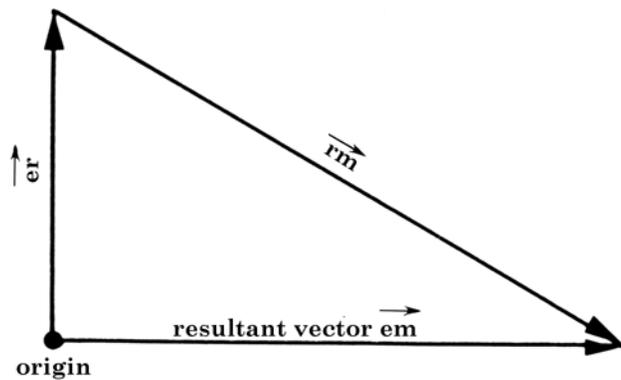


Figure 3.13 - Addition of own ship's true (course-speed) vector and the relative (DRM-SRM) vector to find the true (course-speed) vector of the other ship.

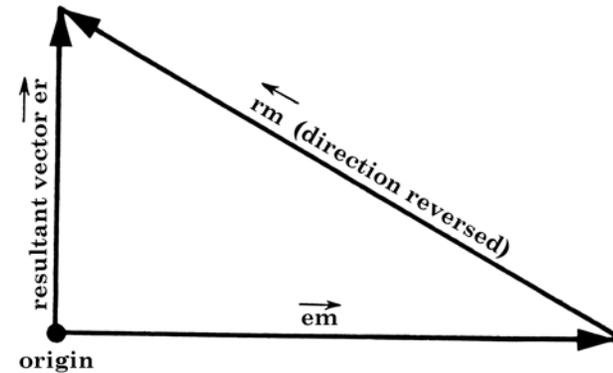


Figure 3.14 - Subtraction of the relative (DRM-SRM) vector from other ship's true (course-speed) vector to find own ship's true (course-speed) vector.

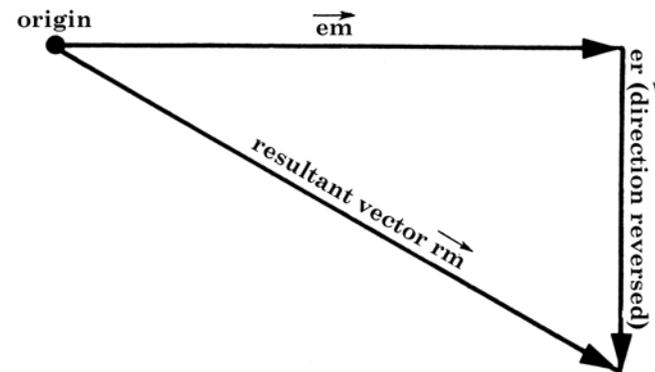


Figure 3.15 - Subtraction of own ship's true (course-speed) vector from other ship's true (course-speed) vector to find the relative (DRM-SRM) vector.

MANEUVERING BOARD

MANEUVERING BOARD FORMAT

The Maneuvering Board is a diagram which can be used in the solution of relative motion problems. Printed in green on white, it is issued in two sizes, 10 inches and 20 inches, charts 5090 and 5091, respectively.

Chart 5090, illustrated in figure 3.16, consists primarily of a polar diagram having equally spaced radials and concentric circles. The radials are printed as dotted lines at 10° intervals. The 10 concentric circles are also dotted except for the inner circle and the outer complete circle, which has a 10-inch diameter. Dotted radials and arcs of concentric circles are also printed in the area of the corners of the 10-inch square framing the polar diagram.

The 10-inch circle is graduated from 0° at the top, through 360° with the graduations at each 10° coinciding with the radials.

The radials between concentric circles are subdivided into 10 equal parts by the dots and small crosses from which they are formed. Except for the inner circle, the arcs of the concentric circles between radials are subdivided into 10 equal parts by the dots and small crosses from which they are formed. The inner circle is graduated at 5° intervals.

Thus, except for the inner circle, all concentric circles and the arcs of concentric circles beyond the outer complete circle are graduated at one-degree intervals.

In the labeling of the outer complete circle at 10° intervals, the reciprocal values are printed inside this circle. For example, the radial labeled as 0° is also labeled as 180° .

In the left-hand margin there are two vertical scales (2:1 and 3:1); in the right-hand margin there are two vertical scales (4:1 and 5:1).

A logarithmic time-speed-distance scale and instructions for its use are printed at the bottom.

Chart 5090 is identical to chart 5091 except for size.

PLOTTING ON MANEUVERING BOARD

If radar targets to be plotted lie within 10 miles of own ship and the distances to these targets are measured in miles, and tenths of miles, the

Maneuvering Board format is particularly advantageous for relatively rapid transfer plotting, i.e., plotting target (radar contact) information transferred from the radarscope.

The extension of the dotted radials and arcs of concentric circles into the corners of the Maneuvering Board permits plotting with the same facility when the distances to the targets are just beyond 10 miles and their bearings correspond to these regions.

In plotting the ranges and bearings of radar targets on the Maneuvering Board, the radar observer generally must select an optimum distance scale. For radar targets at distances between 10 and 20 miles, the 2:1 scale is the best selection, unless the targets can be plotted within the corners of the Maneuvering Board using the 1:1 scale. The objective is to provide as much separation between individual plots as is possible for both clarity and accuracy of plotting.

While generally either the 1:1 or 2:1 scale is suitable for plotting the relative positions of the radar contacts in collision avoidance applications when the ranges are measured in miles, the radar observer also must select a suitable scale for the graphical construction of the vector triangles when the sides of these triangles are scaled in knots.

To avoid confusion between scales being used for distance and speed in knots, the radar observer should make a notation on the Maneuvering Board as to which scale is being used for distance and which scale is being used for speed in knots. However, rapid radar plotting techniques, within the scope of using a selected portion of the relative plot directly as the relative (course-speed) vector, may be employed with the Maneuvering Board.

As illustrated in figure 3.18, the plotting of relative positions on the Maneuvering Board requires the use of a straightedge and a pair of dividers. The distance scale is selected in accordance with the radar range setting. To avoid mistakes, the distance scale used should be circled.

As illustrated in figure 3.19, the construction of own ships true (course-speed) vector scaled in knots and originating from the center of the Maneuvering Board also requires the use of a straightedge and pair of dividers.

In the use of a separate relative plot and vector triangle scaled in knots, the direction of the relative (DRM-SRM) vector must be transferred from the relative plot by parallel rules or by sliding one triangle against another.

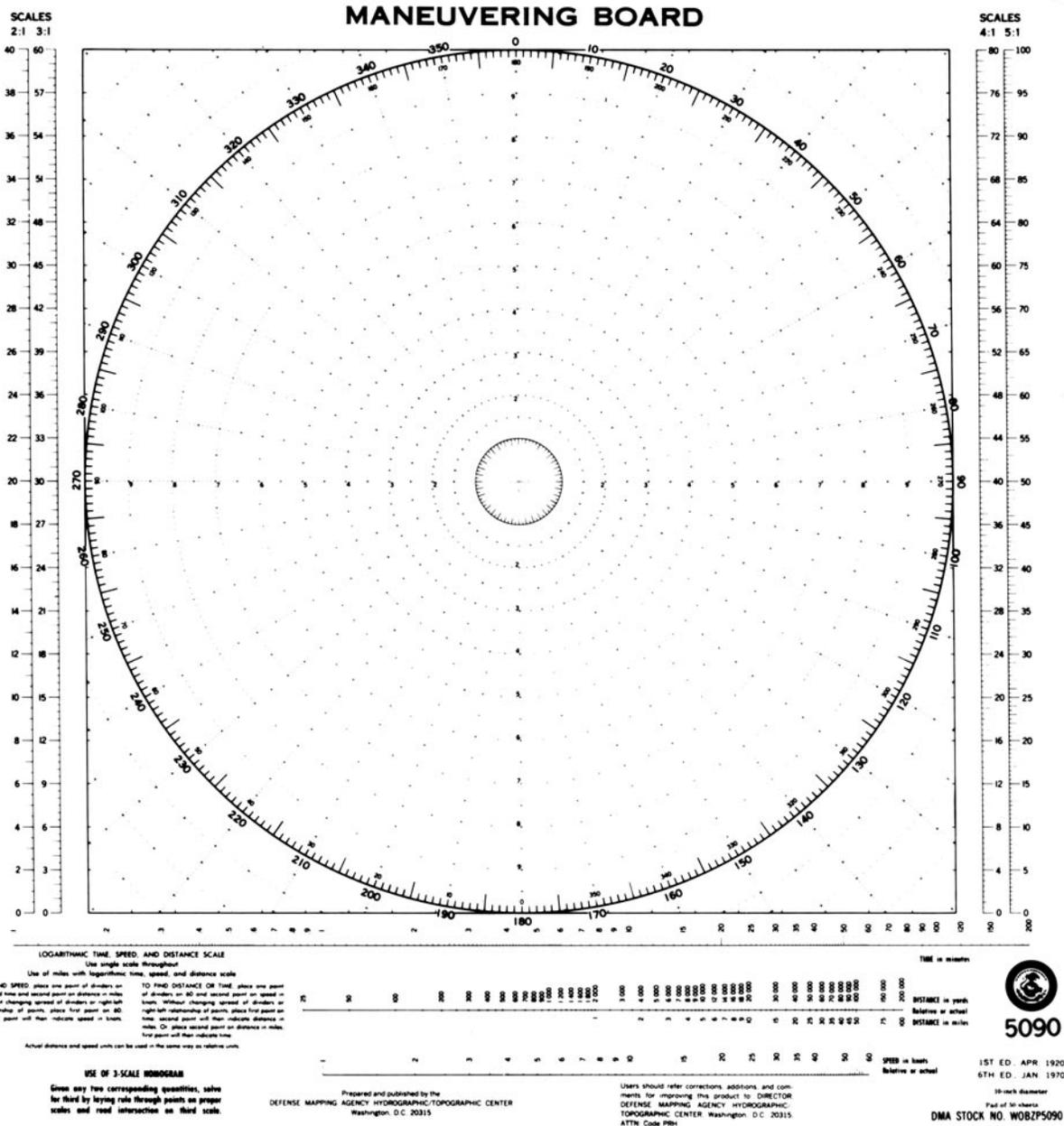


Figure 3.16 - Maneuvering Board.

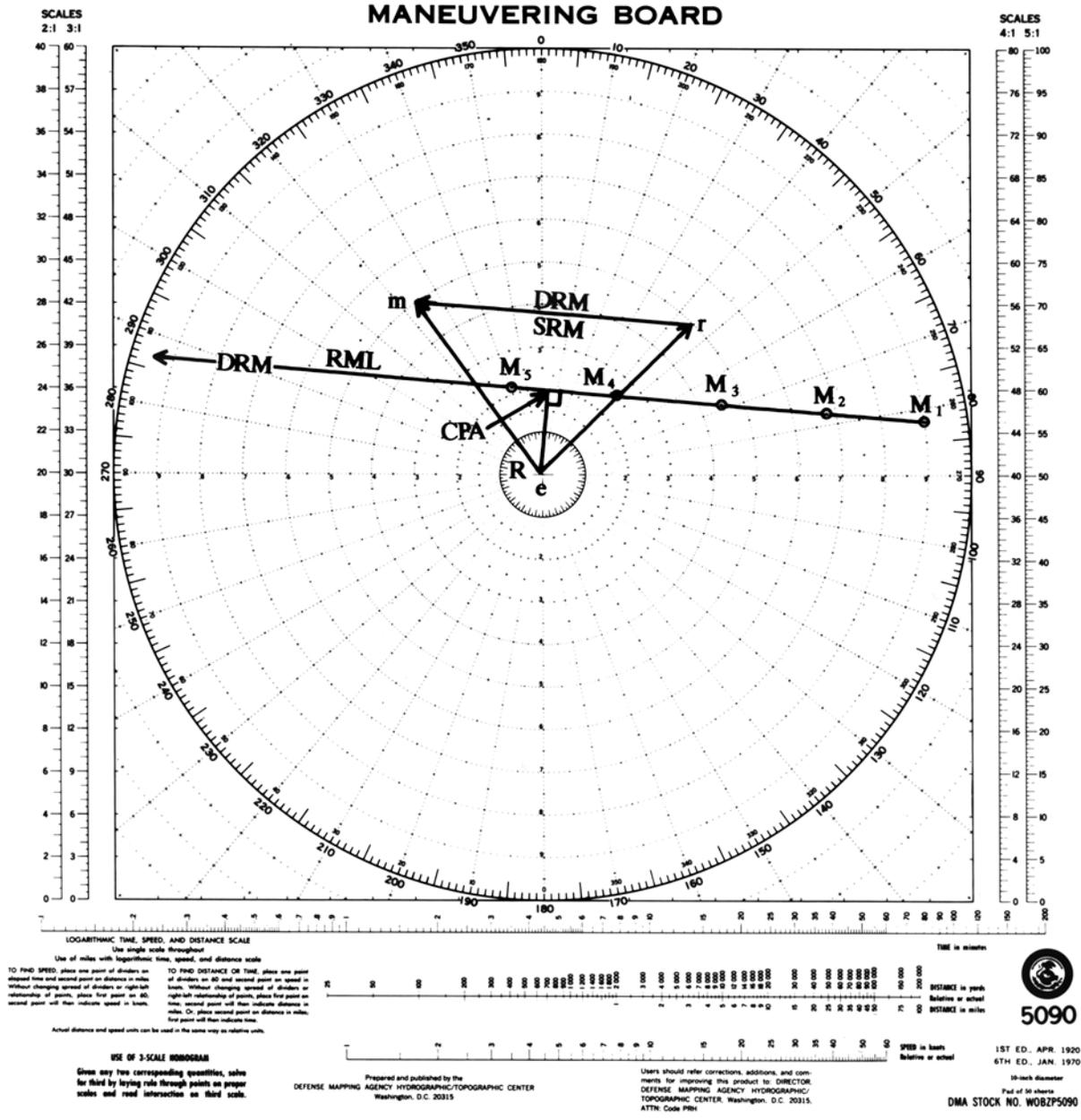


Figure 3.17 - Speed triangle and relative plot on the Maneuvering Board.

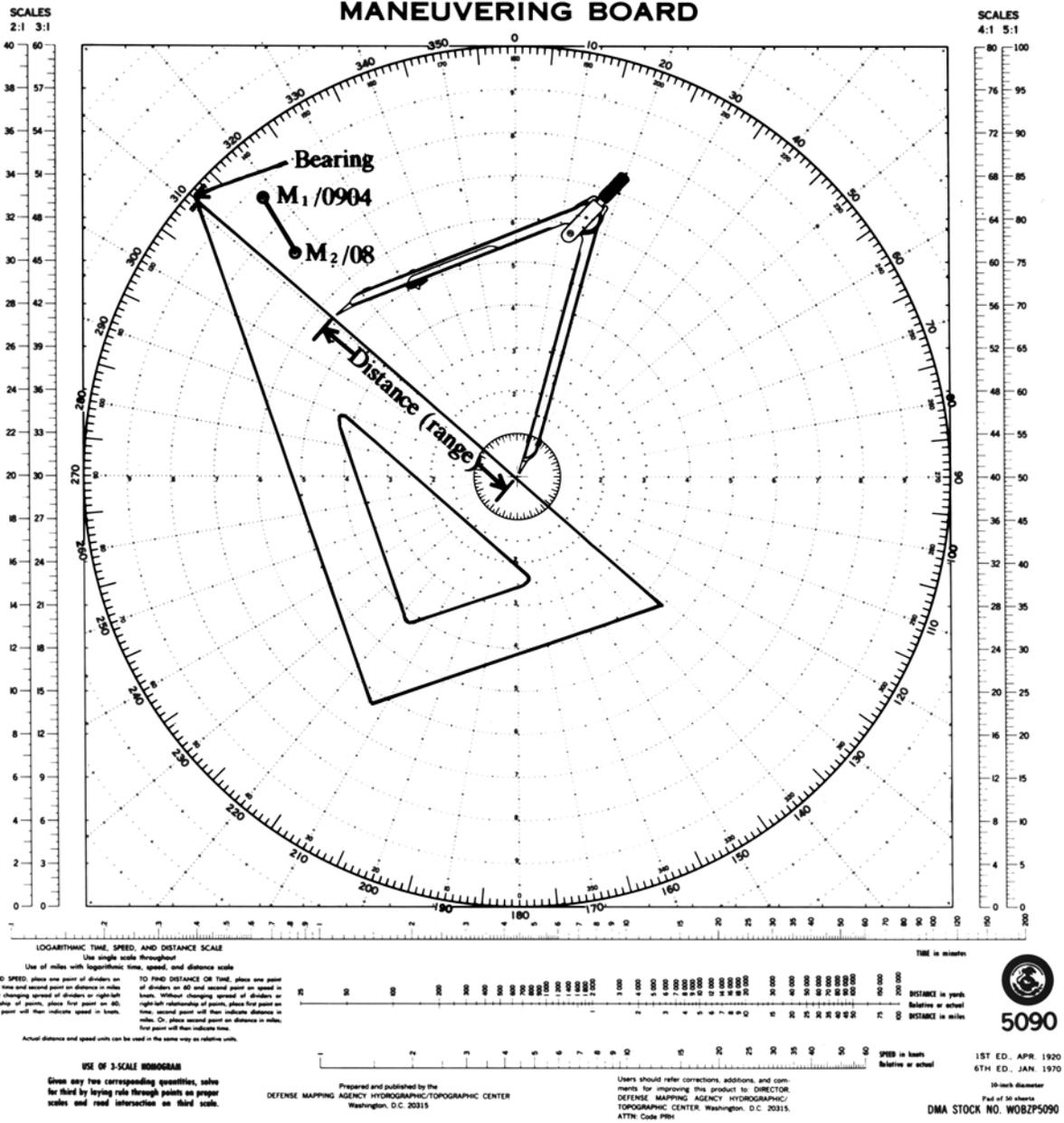


Figure 3.18 - Plotting relative positions on the Maneuvering Board.

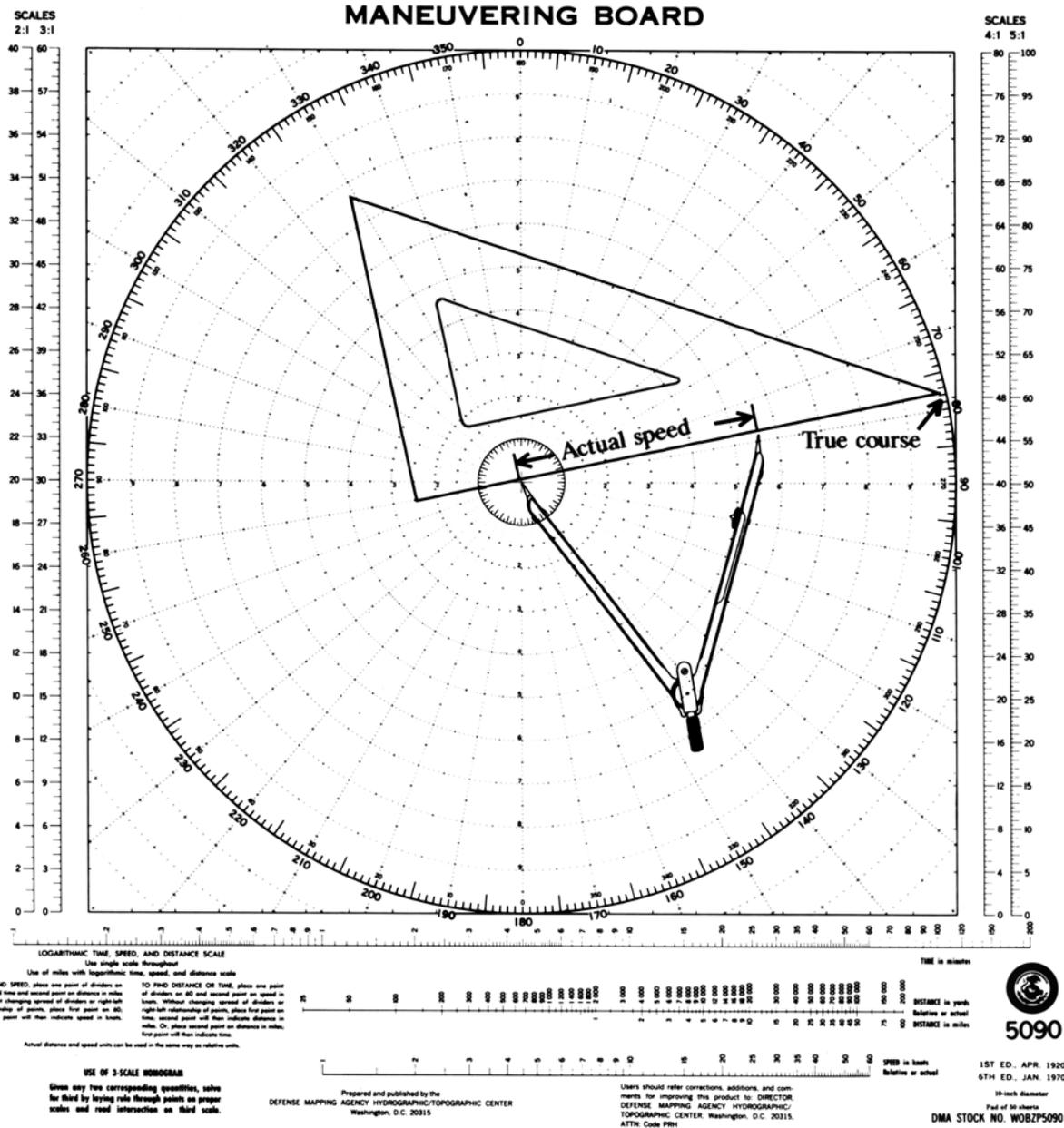


Figure 3.19 - Constructing a true vector on the Maneuvering Board.

Relative Movement Problems

Relative movement problems may be divided into two general categories:

- (1) Tracking: from observed relative movement data, determining the actual motion of the ship or ships being observed.
- (2) Maneuvering: knowing, or having previously determined the actual motion of the ships involved in the problem, ascertaining the necessary changes to actual motion to obtain a desired relative movement.

Three separate and distinct plots are available for the solution of relative movement problems:

- (1) Geographical or navigational plot.
- (2) Relative plot.
- (3) Vector diagram (Speed Triangle).

Each of these plots provides a method either for complete solutions or for obtaining additional data required in the solution of more complex problems.

In the foregoing treatment of the geographical and relative plots, the true and relative vector nature of those plots was illustrated. But in the use of vectors it is usually more convenient to scale the magnitudes of the vectors in knots while at the same time utilizing optimum distance and speed scales for plotting accuracy. Therefore, if the geographical and relative plots are used only for obtaining part of the required data, other means must be employed in completing the solution. This other means is the vector diagram which is a graphical means of adding or subtracting vectors.

When the vector diagram is scaled in knots it is commonly called the Speed Triangle. Figure 3.20 illustrates the construction of a speed triangle in which the true vectors, scaled in knots, are drawn from a common point e (for earth) at the center of the polar diagram. The true vector of the reference ship is er ; the true vector of ship M , commonly called the maneuvering ship, is em , and the relative vector is rm . The vector directions are shown by the arrowheads.

The direction of the relative vector rm in the speed triangle is the same as the DRM in the relative plot. The DRM is the connecting link between the two diagrams. Also, the magnitude (SRM) of the relative vector in the speed triangle is determined by the rate of motion of ship M along the RML of the relative plot.

If in figure 3.20 the true vector of the reference ship were known and the relative vector were derived from the rate and direction of the relative plot, the vectors could be added to obtain the true vector of the maneuvering ship ($\vec{em} = \vec{er} + \vec{rm}$). In the addition of vectors, the vectors are constructed end to end while maintaining vector magnitude and direction. The sum is the magnitude and direction of the line joining the initial and terminal points of the vectors.

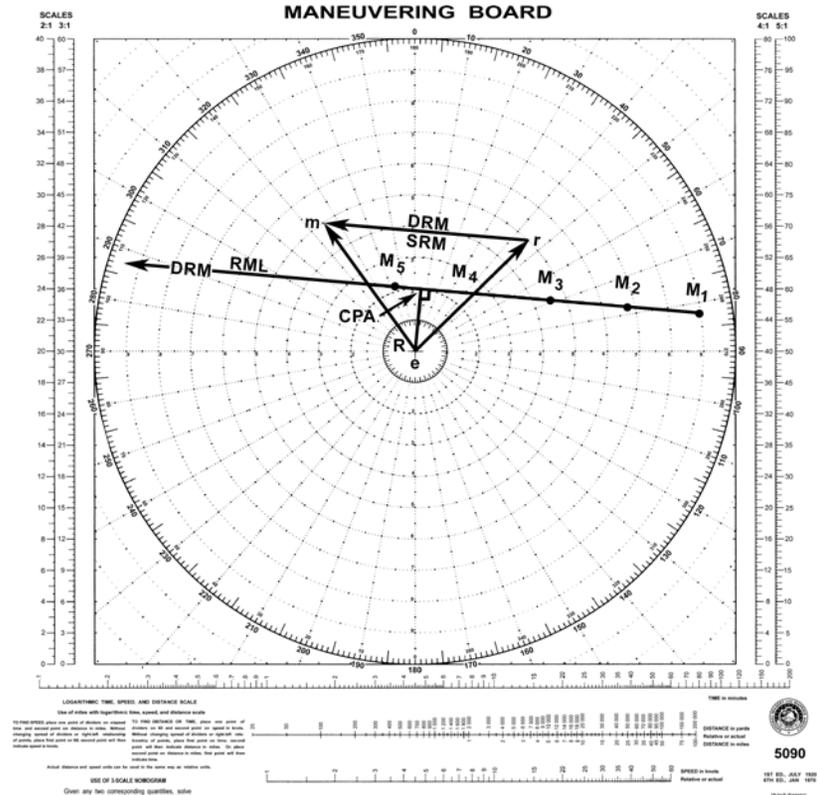


Figure 3.20 - Speed triangle and relative plot.

If in figure 3.20 the true vector of the maneuvering ship were known as well as that of the reference ship, the relative vector could be obtained by subtracting the true vector of the reference ship from the true vector of the maneuvering ship ($\vec{rm} = \vec{em} - \vec{er}$).

In this vector subtraction, the true vectors are constructed end to end as before, but the direction of the reference ship true vector is reversed.

If in figure 3.20 the true vector of the maneuvering ship were known as well as the relative vector, the true vector of the reference ship could be obtained by subtracting the relative vector from the true vector of the maneuvering ship ($\vec{er} = \vec{em} - \vec{rm}$).

But in the practical application of constructing two of the known vectors,

the third vector may be found by completing the triangle. The formulas as such may be ignored as long as care is exercised to insure that the vectors are constructed in the right direction. Particular care must be exercised to insure that the DRM is not reversed. The relative vector rm is always in the direction of the relative movement as shown on the relative plot and always join the heads of the true vectors at points r and m .

Fundamental to this construction of the speed triangle (vector diagram) with the origin of the true vectors at the center of the polar diagram is the fact that the locations where the actual movement is taking place do not affect the results of vector addition or subtraction. Or, for given true courses and speeds of the reference and maneuvering ships, the vector diagram is independent of the relative positions of the ships. In turn, the place of construction of the vector diagram is independent of the position of the relative plot.

In figure 3.20 the vector diagram was constructed with the origins of the true vectors at the center of the polar diagram in order to make most effective use of the compass rose and distance circles in constructing true vectors. But in this application of the vector diagram in which the vector magnitudes are scaled in knots, to determine the true vector of the maneuvering ship an intermediate calculation is required to convert the rate of relative movement to relative speed in knots before the relative vector may be constructed with its origin at the head of the true vector of the reference ship. This intermediate calculation as well as the transfer of the DRM to the vector diagram may be avoided through direct use of the relative plot as the relative vector. In this application the vector diagram is constructed with the true vectors set to the same magnitude scale as the relative vector. This scale is the distance traveled per the time interval of the relative plot.

There are two basic techniques used in the construction of this type of vector diagram. Figures 3.21 and 3.22(a) illustrate the construction in which the reference ship's true vector is drawn to terminate at the initial plot of the segment of the relative plot used directly as the relative vector. The vector diagram is completed by constructing the true vector of the maneuvering ship from the origin of the reference ship's true vector, terminating at the end of the relative vector. Figure 3.22(b) illustrates the construction in which the reference ship's true vector is drawn to originate at the final plot of the segment of the relative plot used directly as the relative vector. The vector diagram is completed by constructing the true vector of the maneuvering ship from the origin of the relative vector, terminating at the head of the reference ship's true vector. In the latter method the advantages of the conventional vector notation are lost. Either method is facilitated through the use of convenient time lapses (selected plotting intervals) such as 3 or 6 minutes, or other multiples thereof, with which well known rules of thumb may be used in determining the vector lengths.

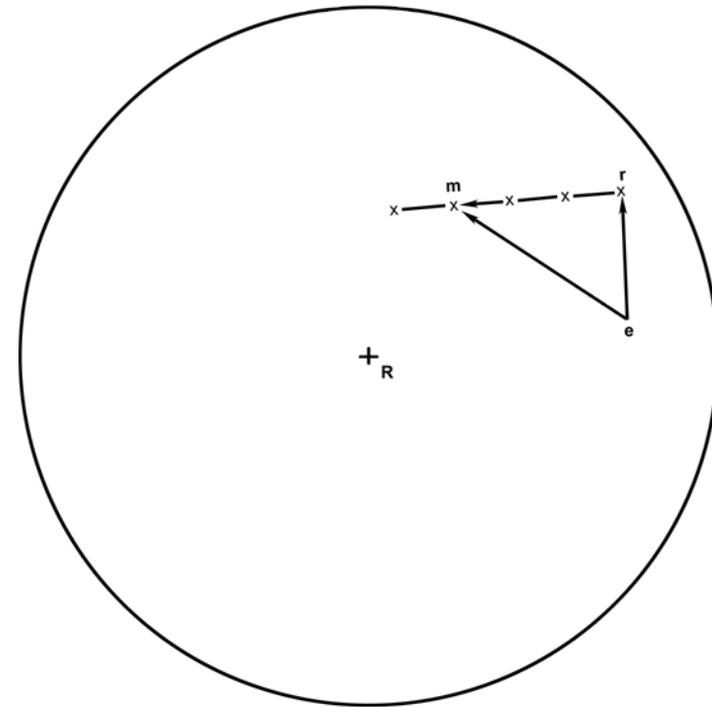


Figure 3.21 - Vector diagram.

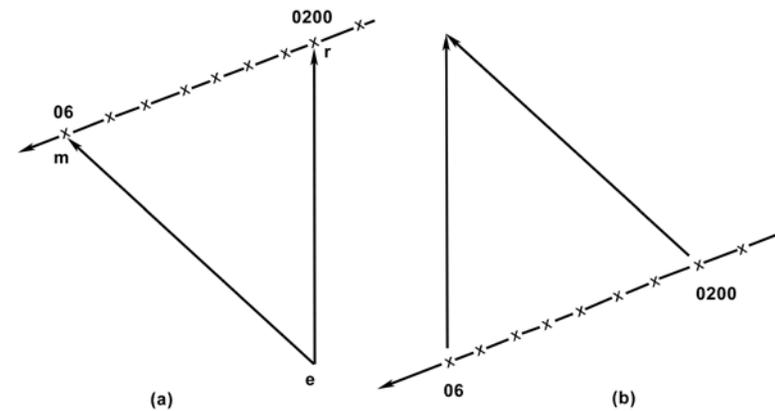


Figure 3.22 - Vector diagrams.

Figure 3.23 illustrates that even though the vector diagram may be constructed initially in accordance with a particular selected plotting interval, the vector diagram subsequently may be subdivided or expanded in geometrically similar triangles as the actual time lapse of the plot differs from that previously selected. If own ship's true vector er is drawn initially for a time lapse of 6 minutes and the actual plot is of 8 minutes duration, vector er is increased in magnitude by one third prior to completing the vector diagram.

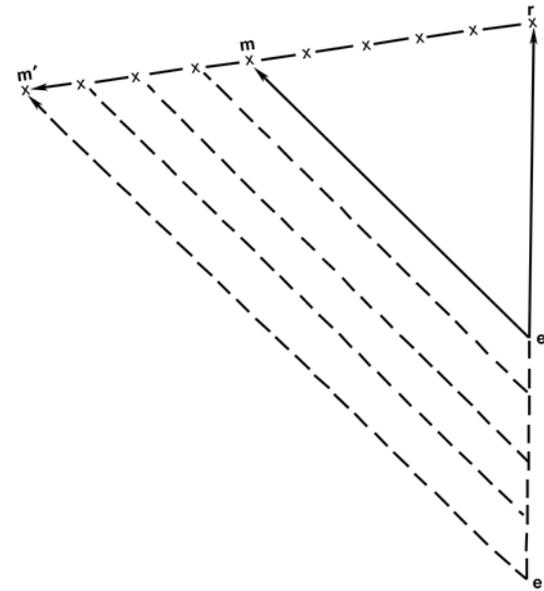


Figure 3.23 - Vector diagram.

THE LOGARITHMIC TIME-SPEED-DISTANCE NOMOGRAM

At the bottom of the Maneuvering Board a nomogram consisting of three equally spaced logarithmic scales is printed for rapid solution of time, speed, and distance problems.

The nomogram has a logarithmic scale for each of the terms of the basic equation:

$$\text{Distance} = \text{Speed} \times \text{Time}$$

The upper scale is graduated logarithmically in minutes of time; the middle scale is graduated logarithmically in both miles and yards; and the lower scale is graduated logarithmically in knots. By marking the values of

two known terms on their respective scales and connecting such marks by a straight line, the value of the third term is found at the intersection of this line with the remaining scale.

Figure 3.24 illustrates a solution for speed when a distance of 4 miles is traveled in 11 minutes. Only one of the three scales is required to solve for time, speed, or distance if any two of the three values are known. Any one of the three logarithmic scales may be used in the same manner as a slide rule for the addition or subtraction of logarithms of numbers. Because the upper scale is larger, its use for this purpose is preferred for obtaining greater accuracy.

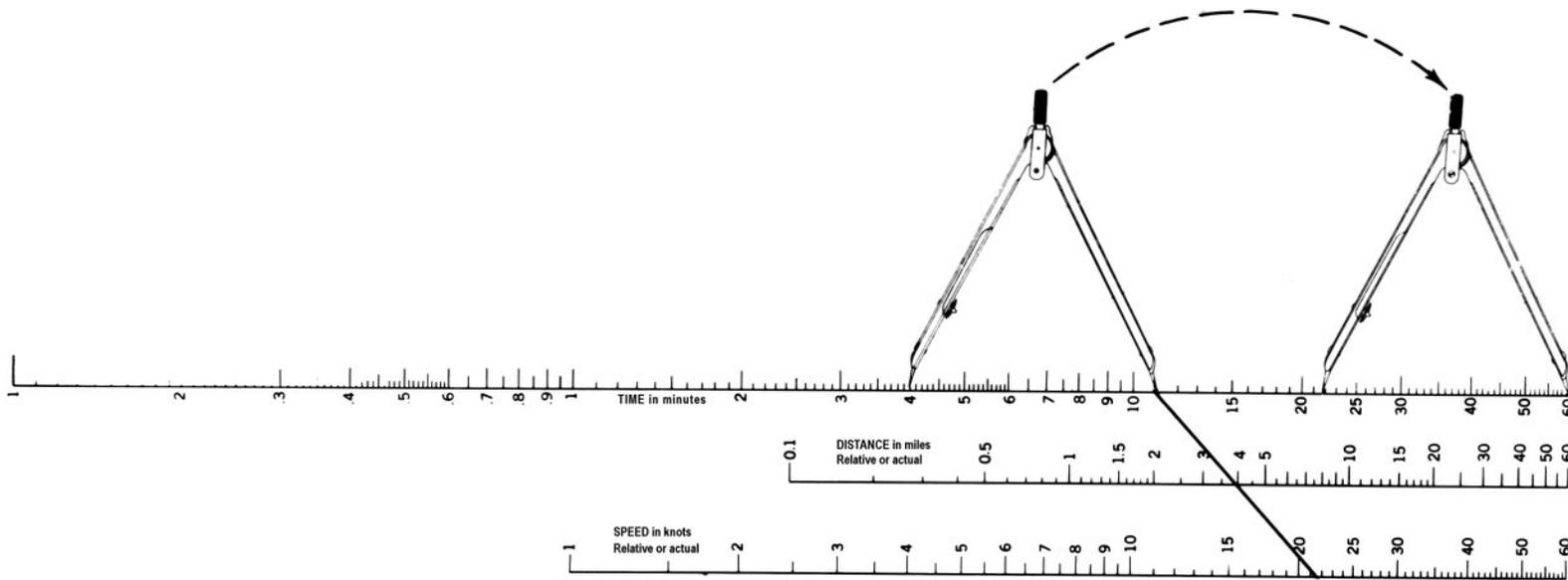


Figure 3.24 - Logarithmic time-speed-distance nomogram.

When using a single logarithmic scale for the solution of the basic equation with speed units in knots and distance units in miles or thousands of yards, either 60 or 30 has to be incorporated in the basic equation for proper cancellation of units.

Figure 3.24 illustrates the use of the upper scale for finding the speed in knots when the time in minutes and the distance in miles are known. In this problem the time is 11 minutes and the distance is 4 miles. One point of a pair of dividers is set at the time in minutes, 11, and the second point at the distance in miles, 4. Without changing the spread of the dividers or the right-left relationship, set the first point at 60. The second point will then indicate the speed in knots, 21.8. If the speed and time are known, place one point at 60 and the second point at the speed in knots, 21.8. Without changing the spread of the dividers or the right-left relationship, place the first point at the time in minutes, 11. The second point then will indicate the distance in miles, 4.

In the method described, there was no real requirement to maintain the right-left relationship of the points of the pair of dividers except to insure that for speeds of less than 60 knots the distance in miles is less than the time in minutes. If the speed is in excess of 60 knots, the distance in miles will always be greater than the time in minutes.

If the distance is known in thousands of yards or if the distance is to be found in such units, a divider point is set at 30 rather than the 60 used with miles. If the speed is less than 30 knots in this application, the distance in thousands of yards will always be less than the time in minutes. If the speed is in excess of 30 knots, the distance in thousands of yards will always be greater than the time in minutes.

For speeds of less than 60 knots and when using a logarithmic scale which increases from left to right, the distance graduation always lies to the left of the time in minutes graduation; the speed in knots graduation always lies to the left of the 60 graduation.

The use of the single logarithmic scale is based upon the fundamental property of logarithmic scales that equal lengths along the scale represent equal values of ratios. For example, if one has the ratio 1/2 and with the dividers measures the length between 1 and 2, he finds the same length between 2 and 4, 5.5 and 11.0, or any other two values one of which is half the other. In using the single logarithmic scale for the solution of a specific problem in which a ship travels 10 nautical miles in 20 minutes, the basic formula is rearranged as follows:

$$\text{Speed} = \frac{\text{Distance (nautical miles)}}{\text{Time (minutes)}} \text{ times } \frac{60 \text{ min.}}{1 \text{ hr.}}$$

On substituting known numerical values and canceling units, the formula is rearranged further as:

$$\frac{\text{Speed (knots)}}{60} = \frac{10}{20}$$

The ratio 10/20 has the same numerical value as the ratio Speed (knots)/60. Since each ratio has the same numerical value, the length as measured on the logarithmic scale between the distance in nautical miles (10) and the time in minutes (20) will be the same as the length between 60 and the speed in knots. Thus, on measuring the length between 10 and 20 and measuring the same length from 60 the speed is found to be 30 knots.

NAUTICAL SLIDE RULES

Several slide rules have been designed for the solution of time, speed, and distance problems. The circular slide rule illustrated in figure 3.25 has distance graduations in both nautical miles and yards. One nautical mile is assumed to be equal to 2,000 yards. On setting two known values to their respective arrowheads, the value sought is found at the third arrowhead. Thus, there is relatively little chance for error in the use of this slide rule. While the nautical miles and yards graduations are differentiated clearly by their numbering, the nautical miles graduations are green and the yards graduations are black. There is a notation on the base of the slide rule with respect to this color code.

There are straight slide rules designed specifically for the solution of time, speed, and distance problems. The fixed and sliding scales are labeled so as to avoid blunders in their use.

GRAPHICAL RELATIVE MOTION SOLUTIONS

This section provides example solutions of typical relative motion problems encountered while avoiding collision at sea. The solutions to these problems may be derived from radar plots made on the PPI, a reflection plotter mounted on the PPI, or from radar plot information transferred to a separate polar plotting diagram such as the Maneuvering Board.

Until recently, transfer plotting techniques or the transfer of radar plot information to a separate polar plotting diagram were given primary emphasis in the training of radar observers. Studies of the increasing numbers of collisions among radar-equipped ships have directed attention to the fact that too many mariners, usually trained only in transfer plotting techniques, were not making effective use of their radars because of a number of factors, including:

- (1) Their performance of multiple duties aboard merchant ships with little if any assistance.
- (2) The problems inherent to transfer plotting, such as the time lag in measuring the ranges and bearings and transferring this data to a separate plot, and the possibility of error in transferring the data.
- (3) Their attention being directed away from the radar indicator and the subsequent movements of the targets and the appearance of new targets on the PPI while recording, plotting, and constructing graphical solutions on a separate plotting diagram.
- (4) In a multiple radar contact situation, the confusion and greater probability for blunders associated with the construction of overlapping vector triangles, the vectors of which must be related to separate relative plots.

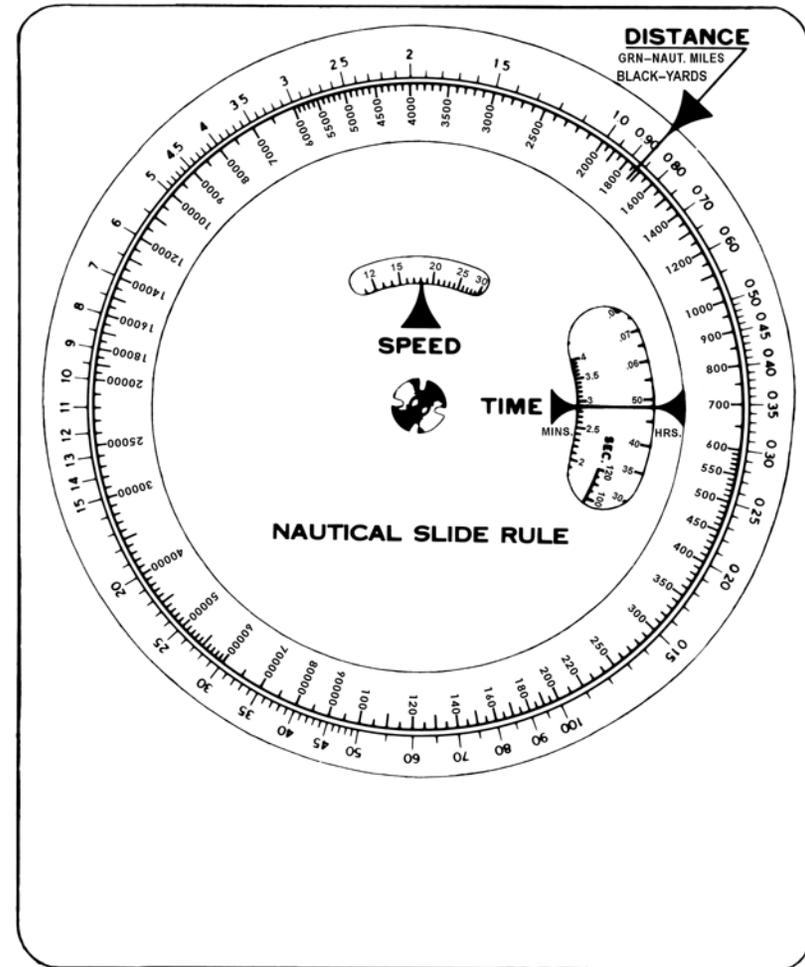


Figure 3.25 - Nautical slide rule.

(5) The general lack of capability of competent radar observers to determine expeditiously initial relative motion solutions for more than about two or three radar contacts imposing possible danger at one time while using conventional transfer plotting techniques. The latter capability generally requires the use of at least two competent radar observers. Evasive action by one or more of the radar contacts may result in an extremely confusing situation, the timely solution of which may not be practicable by means of transfer plotting techniques.

RAPID RADAR PLOTTING

The expression RAPID RADAR PLOTTING is descriptive of techniques used to obtain solutions to relative motion problems by making the required graphical constructions on the PPI or reflection plotter as opposed to the use of a separate plotting diagram for these constructions. These techniques make *direct* use of the *timed* relative motion plot on the PPI as the relative (DRM-SRM) vector. The other two vectors of the vector triangle are scaled in accordance with the scale of the relative (DRM-SRM) vector. Thus, the magnitudes of all vectors are governed by the same interval of time, the distance scale of the radar range setting, and the respective rates of movement.

The direct use of the timed relative motion plot as the relative (DRM-SRM) vector eliminates the necessity for making measurements of the bearings and ranges of the radar targets for plotting on a separate diagram.

This information is obtained simply by marking the target pips on the PPI by grease pencil. Thus, rapid radar plotting techniques, when feasible, permit the radar observer to employ simpler procedures while being able to devote more time to radar observation.

TRANSFER PLOTTING

Relative motion solutions derived from radar data transferred to a plotting diagram can be determined through the direct use of a timed segment of the relative plot as the relative (DRM-SRM) vector of the vector triangle as in rapid radar plotting. Usually, however, the vector triangle is scaled in knots with the origin of each true vector at the center of the plotting diagram. In this transfer plotting technique, the separate relative plot and vector triangle are related in that the relative (DRM-SRM) vector of the vector triangle scaled in knots is derived from the relative plot.

As illustrated in figure 3.26, own ship's true (course-speed) vector *er* is constructed from the center of the Maneuvering Board in the direction of

own ship's true course (090°) with its magnitude scaled in knots. The 2:1 scale in the left margin is used for scaling the vectors of the vector triangle (speed triangle) in knots. Using a pair of dividers, own ship's speed of 12 knots is picked off the 2:1 scale to determine the length of vector *er*.

Using the distance scale on which the relative plot is based, i.e., the 2:1 scale (circled as an aid in avoiding the subsequent use of the wrong distance scale), the relative distance between timed plots $M_1/0720$ and $M_2/29$ is measured as 3.3 miles. With other ship M having moved 3.3 miles in 9 minutes relative to own ship R, the speed of relative movement (SRM) is 22 knots.

Since the direction of the relative (DRM-SRM) vector is that of the direction of relative movement (DRM), i.e., the direction along the relative movement line (RML) from M_1 to M_2 , all information needed for constructing the relative (DRM-SRM) vector is available.

Transferring the DRM from the relative plot by parallel rulers or other means, a line is drawn from the extremity of own ship's true (course-speed) vector *er* in the same direction as the DRM. The length of the relative vector *rm* is taken from the 2:1 scale used in constructing own ship's true vector *er*. The true (course-speed) vector of other ship M, vector *em*, is found by completing the triangle. The speed of other ship M in knots is found by setting the length of the vector *em* to the 2:1 scale.

SELECTION OF PLOTTING TECHNIQUES

The primary advantage of transfer plotting is the higher accuracy afforded by the large vector triangles scaled in knots. Also, the plotting diagrams used provide a permanent record. For a specific situation, the selection of the basic technique to be used should be based upon the relative advantages and disadvantages of each technique as they pertain to that situation. While the individual's skill in the use of a particular technique is a legitimate factor in technique selection, the competent radar observer should be skilled in the use of both basic techniques, i.e., transfer plotting and rapid radar plotting.

During daylight when the hood must be mounted over the PPI, the rapid radar plotting technique generally is not practical. Even with hand access holes in the hood, direct plotting generally is too awkward to be feasible for reasonably accurate solutions. However, the use of a blackout curtain instead of a hood enables the use of the rapid radar plotting technique during daylight as long as the curtain adequately shields the PPI from ambient light. Since most hood designs do not permit more than one observer to view the radarscope at one time, blackout curtain arrangements which permit more than one observer to view the radarscope at one time should enable safer radar observation than hood designs which limit observation to one observer.

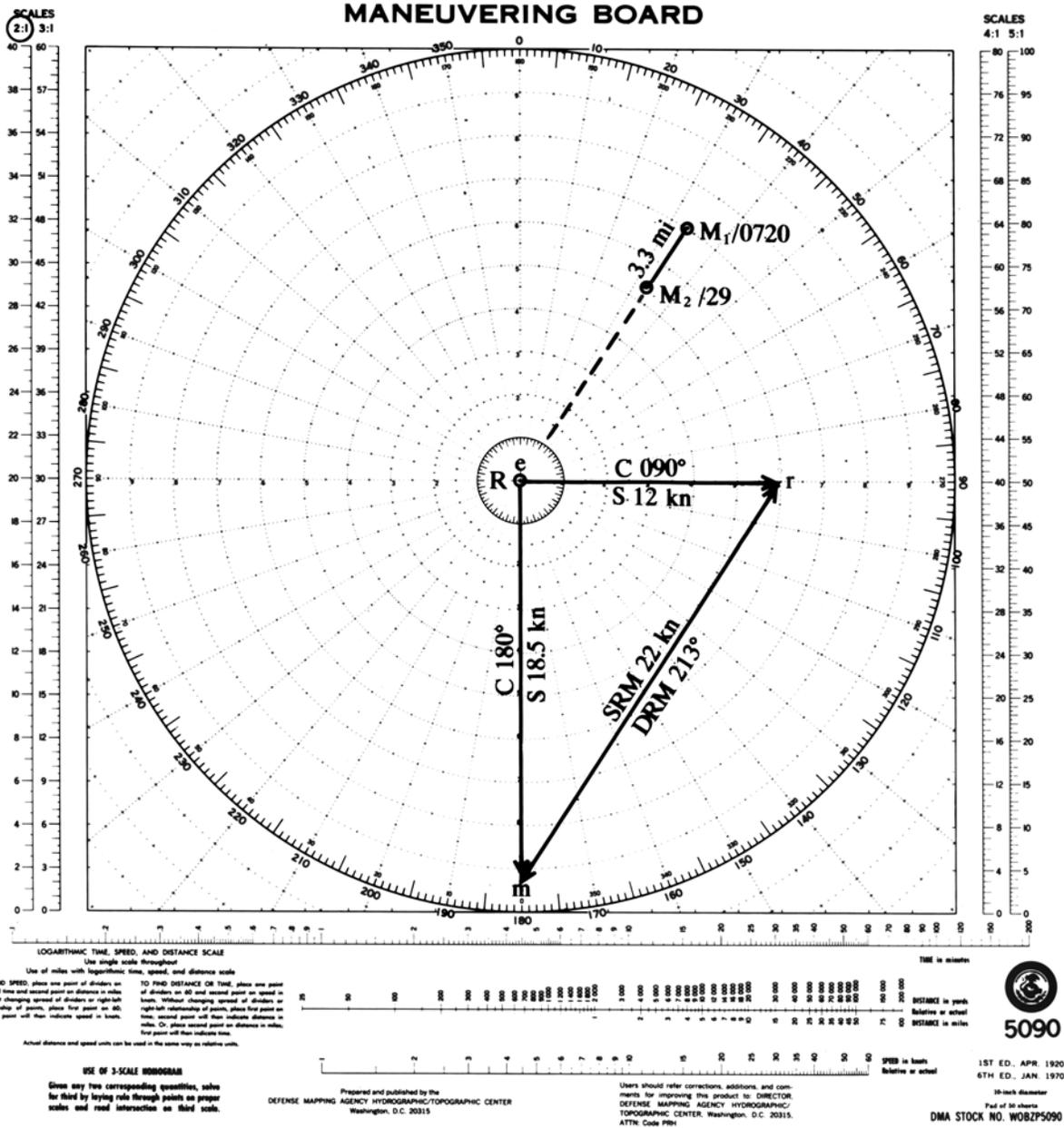


Figure 3.26 - Determining the true course and speed of the other ship by transfer plotting.

The use of rapid radar plotting techniques in a multiple radar contact situation should tend to reduce solution mistakes or blunders because of the usual separation of the vector triangles. Through constructing the vector triangles directly on the PPI or reflection plotter, the probability of timely detection of new contacts and any maneuvers of contacts being plotted should be greater while using rapid radar plotting techniques than while using transfer plotting.

Should the radar observer choose to use a separate plotting sheet for each of the contacts in a multiple radar contact situation to avoid any overlapping of vector triangles in transfer plotting, this multiple usage of plotting sheets can introduce some difficulty in relating each graphical solution to the PPI display. Through constructing the vector triangles directly on the PPI display, the graphical solutions can be related more readily to the PPI display. Also, the direct plotting is compatible with a technique which can be used to evaluate the effect of any planned evasive action on the relative movements of radar contacts for which true course and speed solutions have

not been obtained.

The foregoing discussion of the comparative advantages of rapid radar plotting over transfer plotting in a multiple radar contact situation does not mean to imply that rapid radar plotting techniques always should be used whenever feasible. Each basic technique has its individual merits. In some situations, the more accurate solutions afforded by transfer plotting may justify the greater time required for problem solution. However, the radar observer should recognize that the small observational and plotting errors normally incurred can introduce significant error in an apparently accurate transfer plotting solution. A transfer plotting solution may indicate that a contact on a course nearly opposite to that of own ship will pass to starboard while the actual situation is that each ship will pass port to port if no evasive action is taken. If in this situation own ship's course is changed to the left to increase the CPA to starboard, the course of the other ship may be changed to its right to increase the CPA of a correctly evaluated port passing. Such action taken by own ship could result in a collision.

RADAR PLOTTING SYMBOLS

(See Alternative Radar Plotting Symbols)

RELATIVE PLOT

Symbol	Meaning
R	Own Ship.
M	Other Ship.
M ₁	First plotted position of other ship.
M ₂ , M ₃	Later positions of other ship.
M _x	Position of other ship on RML at planned time of evasive action; point of execution.
NRML	New relative movement line.
RML	Relative movement line.
DRM	Direction of relative movement; always in the direction of M ₁ → M ₂ → M ₃
SRM	Speed of relative movement.
MRM	Miles of relative movement; relative distance traveled.
CPA	Closed point of approach.

VECTOR TRIANGLE

Symbol	Meaning
<i>e</i>	The origin of any ship's true (course-speed) vector; fixed with respect to the earth.
<i>r</i>	The end of own ship's true (course-speed) vector, <i>er</i> ; the origin of the relative (DRM-SRM) vector, <i>rm</i> .
<i>r</i> ₁ , <i>r</i> ₂	The ends of alternative true (course-speed) vectors for own ship.
<i>er</i>	Own ship's true (course-speed) vector.
<i>m</i>	The end of other ship's true (course-speed) vector, <i>em</i> ; the end of the relative (DRM-SRM) vector, <i>rm</i> .
<i>em</i>	Other ship's true (course-speed) vector.
<i>rm</i>	The relative (DRM-SRM) vector; always in the direction of M ₁ → M ₂ → M ₃

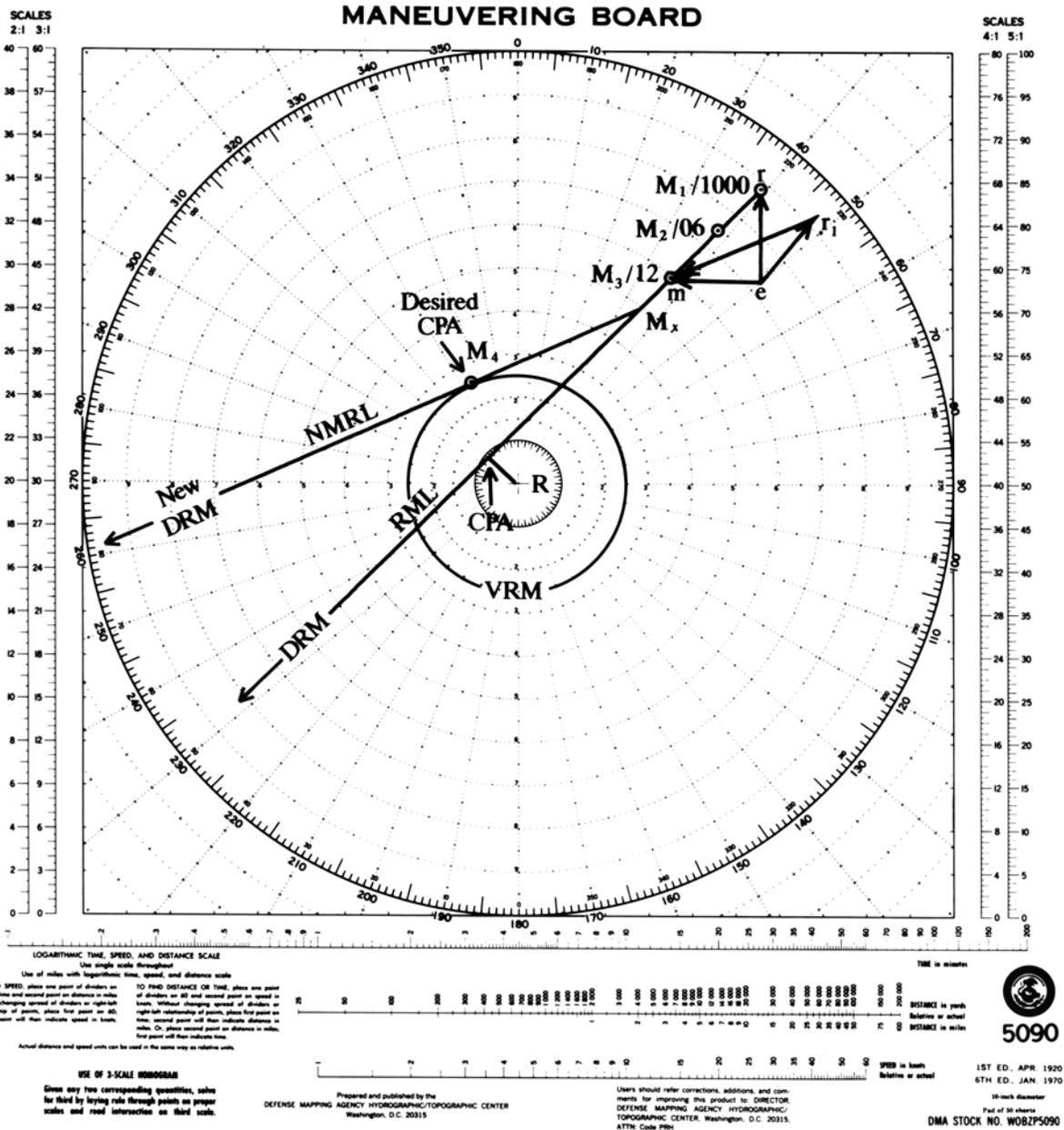


Figure 3.28 - Examples of use of radar plotting symbols.

GRAPHICAL SOLUTIONS ON THE REFLECTION PLOTTER RAPID RADAR PLOTTING

CLOSEST POINT OF APPROACH

To determine the closest point of approach (CPA) of a contact by graphical solution on the reflection plotter, follow the procedure given below.

- (1) Plot at least three relative positions of the contact. If the relative positions lie in a straight or nearly straight line, fair a line through the relative positions. Extend this relative movement line (RML) past the center of the PPI.
- (2) Crank out the variable range marker (VRM) until the ring described by it is tangent to the RML as shown in figure 3.29. The point of tangency is the CPA.
- (3) The range at CPA is the reading of the VRM counter; the bearing at CPA is determined by means of the mechanical bearing cursor, parallel-line cursor, or other means for bearing measurement from the center of the PPI.

Note: The RML should be reconstructed if the contact does not continue to plot on the RML as originally constructed.

TRUE COURSE AND SPEED OF CONTACT

To determine the true course and speed of a contact by graphical solution on the reflection plotter, follow the procedure given below.

- (1) As soon as possible after a contact appears on the PPI, plot its relative position on the reflection plotter. Label the position with the time of the observation as shown in figure 3.29. When there is no doubt with respect to the hour of the plot, it is only necessary to show the last two digits, i.e., the minutes after the hour. In those instances where an unduly long wait would not be required it might be advantageous to delay starting the *timed* plot until the time is some tenth of an hour..., 6 minutes, 12 minutes, 18 minutes, etc., after the hour. This timing could simplify the use of the 6-minute plotting interval normally used with the rapid radar plotting technique.
- (2) Examine the relative plot to determine whether the contact is on a steady course at constant speed. If so, the relative positions plot in a straight or nearly straight line; the relative positions are equally

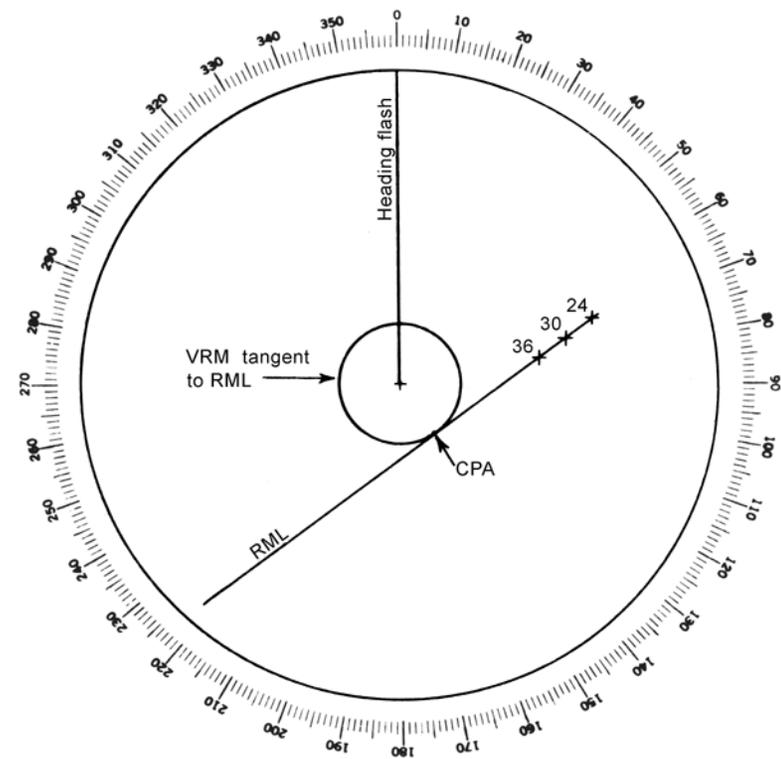


Figure 3.29 - Closest point of approach.

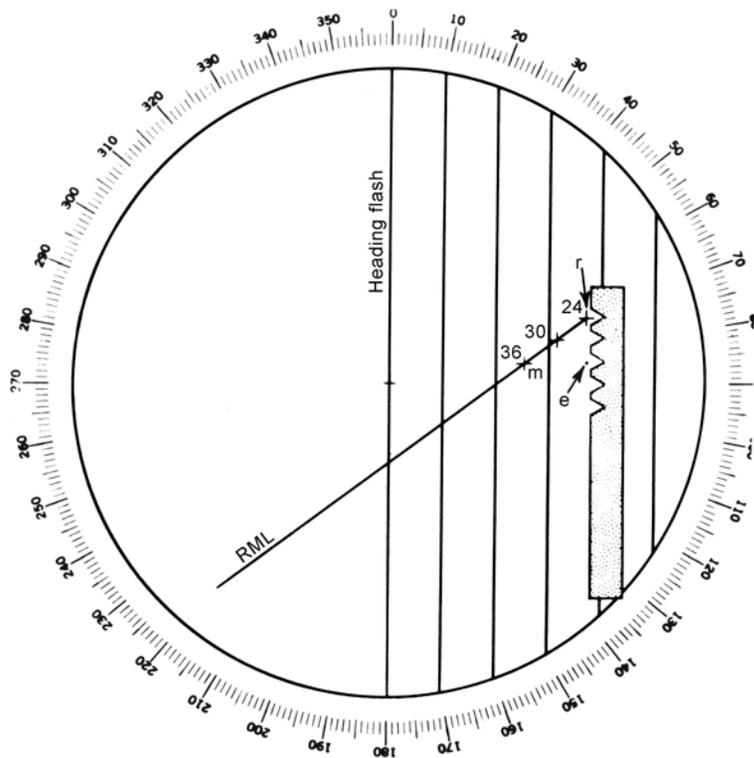


Figure 3.30 - Use of the notched plastic rule.

- (3) With the contact on a steady course at constant speed, select a suitable relative position as the origin of the relative speed (DRM-SRM) vector; label this plot r as shown in figure 3.30.
- (4) Crank the parallel-line cursor until its lines are parallel to the heading flash. As shown in figure 3.30, place the appropriate plastic rule so that one notch is at r and its straightedge is parallel to the lines of the cursor and the heading flash. The rule is scaled for a 6-minute run between notches.
- (5) Select the time interval for the solution, 12 minutes for example. Accordingly, the origin e of own ship's true (course-speed) vector er is at the second notch from r ; m , the head of the contact's true (course-

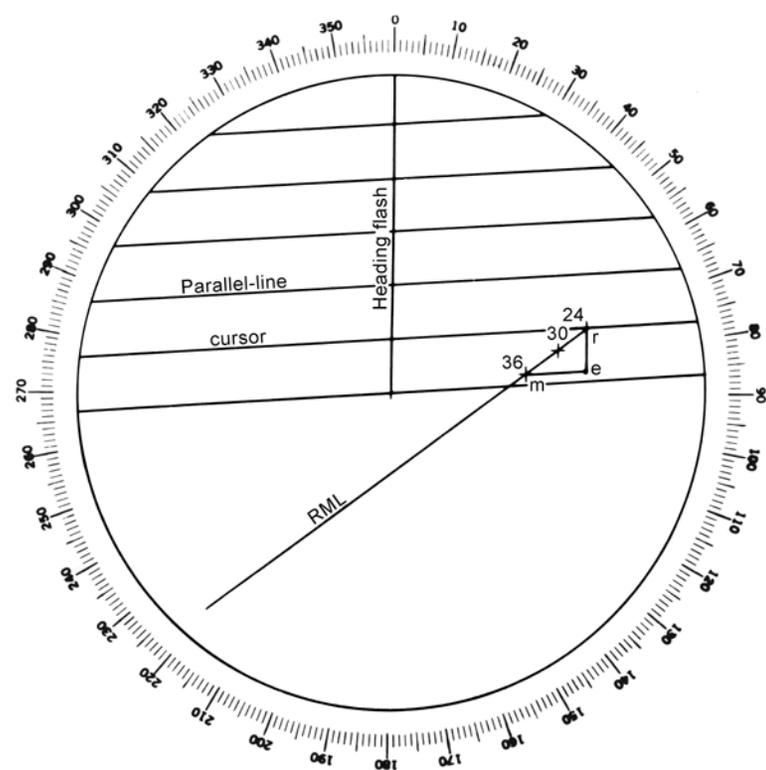


Figure 3.31 - Use of parallel-line cursor to find true course of contact.

- speed) vector, is at the plot 12 minutes beyond r in the direction of relative movement.
- (6) Construct the contact's true (course-speed) vector em .
- (7) Crank the parallel-line cursor so that its lines are parallel to vector em as shown in figure 3.31. The contact's true course is read on the true bearing dial using the radial line of the parallel-line cursor; the contact's true speed is estimated by visual comparison with own ship's true vector er . For example if em is about two-thirds the length of er , the contact's speed is about two-thirds own ship's speed. Or, the notched rule can be used to determine the speed corresponding to the length of em .

COURSE TO PASS AT SPECIFIED CPA

The procedure for determining own ship's new course and/or speed to reduce the risk of collision is given below.

(1) Continuing with the plot used in finding the true course and speed of the contact, mark the point of execution (M_x) on the RML as shown in figure 3.32. M_x is the position of the contact on the RML at the planned time of evasive action. This action may be taken at a specific clock time or when the range to the contact has decreased to a specified value.

(2) Crank the VRM to the desired distance at CPA. This is normally the distance specified for the **danger** or **buffer zone**. If the fixed range rings are displayed and one range ring is equal to this distance, it will not be necessary to use the VRM.

(3) From M_x draw the new RML tangent to the VRM circle. Two lines can be drawn tangent to the circle, but the line drawn in figure 3.32 fulfills the requirement that the contact pass ahead of own ship. If the new RML crosses the heading flash, the contact will pass ahead.

To avoid parallax, the appropriate sector of the VRM may be marked on the reflection plotter and the new RML drawn to it rather than attempting to draw the new RML tangent to the VRM directly.

(4) Using the parallel-line cursor, draw a line parallel to the new RML through m or the final plot (relative position) used in determining the course and speed of the contact. This line is drawn from m in a direction opposite to the new DRM because the new relative speed (DRM-SRM) vector will be parallel to the new RML and the head (m) of the new vector ($r'm$) will lie in the new DRM away from the origin, r' .

(5) Avoiding by course change only, the magnitude of own's true (course-speed) vector remains constant. Therefore, the same number of notches on the plastic ruler used for own ship's true vector for the contact's course and speed solution are used for own ship's new true vector er' . With one notch set at e , the ruler is adjusted so that the third notch away intersects the line drawn parallel to the new RML. As shown in figure 3.28, the intersection at r' is the head of the required new true vector for own ship (er'); it is the origin of the new relative speed vector, $r'm$.

The previously described use of the plastic ruler, in effect, rotates vector er about its origin; the head of the vector describes an arc which intersects the line drawn parallel to the new RLM at r' .

If the speed of the contact were greater than own ship's speed, there would be two intersections and, thus, two courses available to produce the desired distance at CPA. Generally, the preferred course is that which results in the higher relative speed (the longer relative speed vector) in order to expedite safe passing.

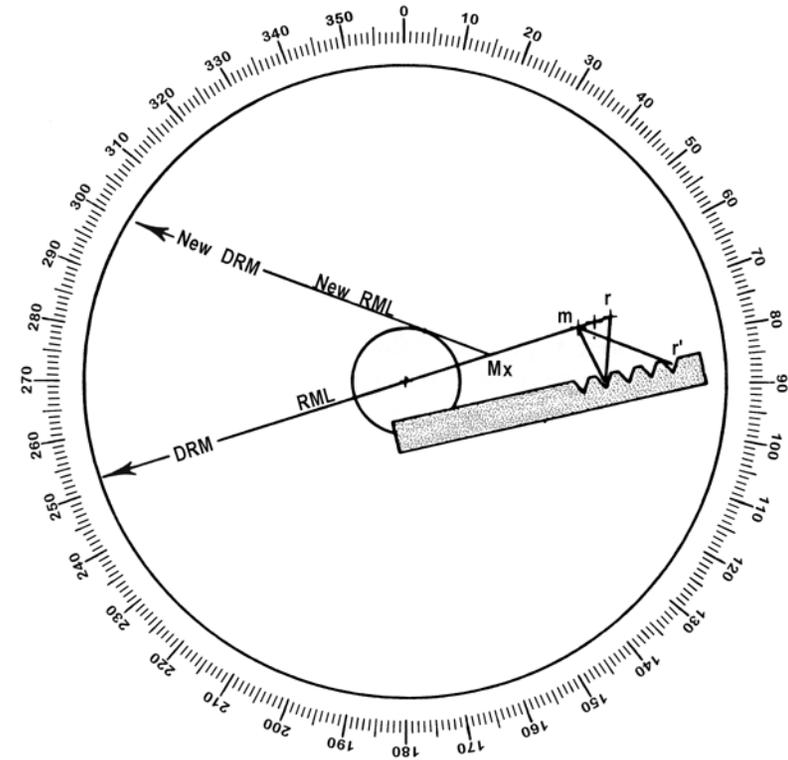


Figure 3.32 - Evasive action.

SPECIAL CASES

In situations where contacts are on courses opposite to own ship's course or are on the same course as own ship but at slower or higher speeds, the relative movement lines are parallel to own ship's course line. If a contact has the same course and speed as own ship, there is no relative movement line; all relative positions lie at one point at a constant true bearing and distance from own ship. If a contact is stationary or dead in the water, the relative vector rm and own ship's true vector er are equal and opposite, and coincident. With e and m coincident, there is no vector em .

The solutions of these special cases can be effected in the same manner as those cases resulting in the conventional vector triangle. However, no vector triangle is formed; the vectors lie in a straight line and are coincident.

In figure 3.33 contacts A, B, C, and D are plotted for a 12-minute interval; own ship's true vector er is scaled in accordance with this time. Inspection of the plot for contact A reveals that the DRM is opposite to own ship's course;

the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact B reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed minus the contact's speed. The contact is on the same course as own ship at about one-half own ship's speed.

Inspection of the plot for contact C reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact D reveals that the DRM is the same as own ship's course; the relative speed is equal to the contact's speed minus own ship's speed. The contact is on the same course as own ship at about twice own ship's speed.

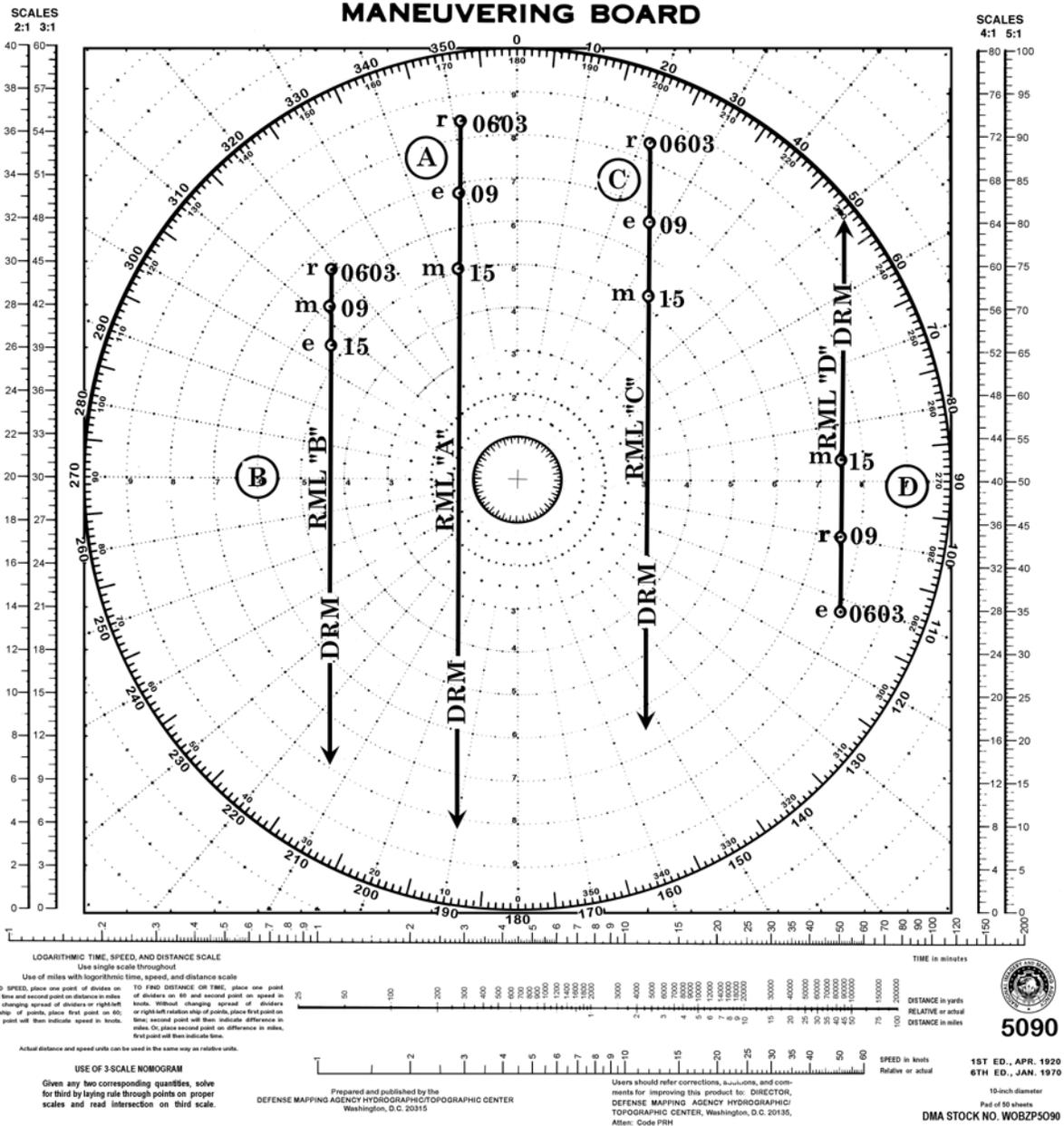


Figure 3.33 - Special cases.

CONSTRUCTING THE PLASTIC RULE USED WITH RAPID RADAR PLOTTING

When plotting by the rapid radar plotting technique, a colored 6 to 8-inch flexible plastic straightedge is normally used to construct the vectors and other line segments on the reflection plotter. The following procedure can be used to construct the desired scale for vector magnitudes on the straightedge.

- (1) Switch the radar indicator to an appropriate plotting range, 24 miles for example.
- (2) Crank out the variable range marker (VRM) to an integral value of range, 5 miles for example. Mark the reflection plotter at the intersection of the VRM and the heading flash as shown in figure 3.34. This point will represent zero on the scale to be constructed for subsequent transfer to the plastic strip.
- (3) Compute the distance own ship will travel in 6 minutes at a speed expected to be used in collision avoidance. At a speed of 21 knots, own ship will travel 2.1 miles in 6 minutes.
- (4) Since the zero mark is at 5 miles on the PPI, crank out the VRM to 7.1 miles and mark the reflection plotter at the intersection of the VRM and the heading flash to obtain the scale spacing for 2.1 miles. Repeat this procedure with the VRM set at 9.2, 11.3, and 13.4 miles to obtain other scale graduations 2.1 miles apart. The length between scale marks at 5.0 and 7.1 miles provides the magnitude of 6-minute vectors at 21 knots; the length between scale marks at 5.0 and 9.2 provides the magnitudes of 12-minute vectors at 21 knots, etc.
- (5) As shown in figure 3.35, lay the plastic strip adjacent to the graduation marks on the reflection plotter and parallel to the heading flash. Extend the grease pencil marks onto the plastic strip. With the scale transferred to the plastic strip, a permanent rule is made by notching the scale on the plastic strip. The notches in the rule shown in figure 3.35 have been drawn large and angular for illustration purposes only. They should be about the size and shape of the cross-section of the lead used in the grease pencil.
- (6) Several rules are normally used, each graduated for a particular range scale setting and own ship speed. The range and speed should be prominently marked on each rule.

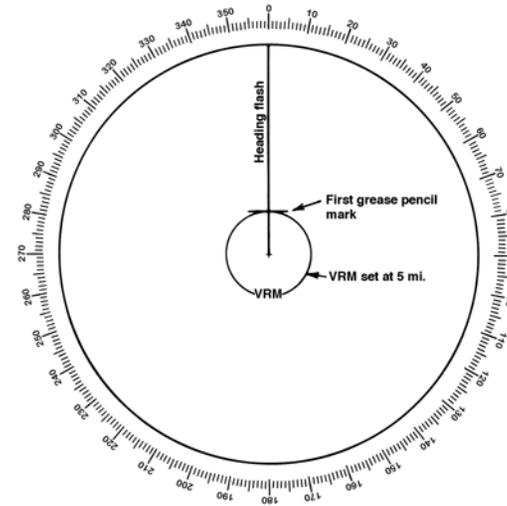


Figure 3.34 - Constructing the scale.

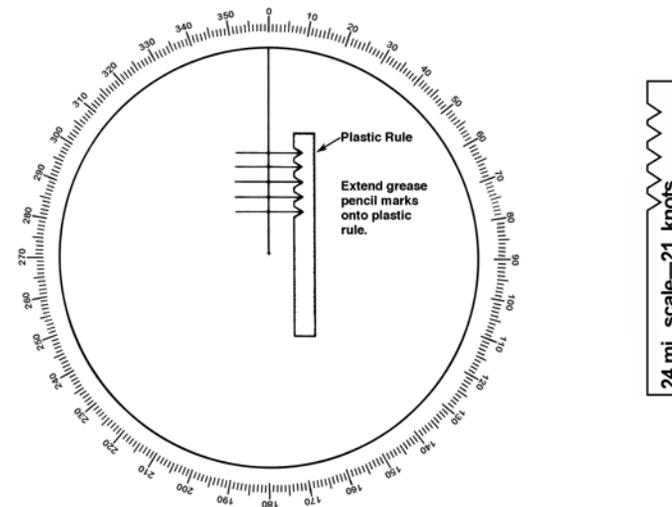


Figure 3.35 - Graduating the rule.

EXAMPLES

e-r-m TRIANGLE

- EXAMPLE 1 . DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)
- EXAMPLE 2 . COURSE AND SPEED OF A RADAR CONTACT
- EXAMPLE 3 . COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD
- EXAMPLE 4 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own Ship's Speed is Greater Than That of Other Ship
- EXAMPLE 5 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own Ship's Speed is Less Than That of Other Ship
- EXAMPLE 6 . VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER
- EXAMPLE 7 . AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING TRUE COURSES AND SPEEDS
OF THE CONTACTS
- EXAMPLE 8 . DETERMINING THE CLOSEST POINT OF APPROACH FROM THE GEOGRAPHICAL PLOT

EXAMPLE 1

DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)

Situation:

With own ship on course 070° and the radar set on the 12-mile range scale, other ship M is observed as follows:

<i>Time</i>	<i>Bearing</i>	<i>Range (miles)</i>	<i>Rel. position</i>
1000	050°	9.0	M1
1006	049°	7.5	M2
1012	047°	6.0	M3

Required:

- (1) Direction of relative movement (DRM).
- (2) Speed of relative movement (SRM).
- (3) Bearing and range at closest point of approach (CPA).
- (4) Estimated time of arrival at CPA.

Solution:

- (1) Plot and label the relative positions, M₁, M₂, and M₃, using the 1:1 scale; fair a line through the relative positions; extend this line, the *relative movement line (RML)*, beyond the center of the Maneuvering Board.
- (2) The direction of the RML from the initial plot M₁, is the direction of

relative movement (DRM): 236°.

(3) Measure the relative distance (MRM) between any two timed plots on the RML, preferably between the two best plots with the greatest time separation. In this instance, measure the distance between M₁ and M₃: 3.0 miles. Using the corresponding time interval (1000 - 1012 = 12m), obtain the speed of relative movement (SRM) from the Logarithmic Time-Speed-Distance Scale at the bottom of the Maneuvering Board: 15 knots.

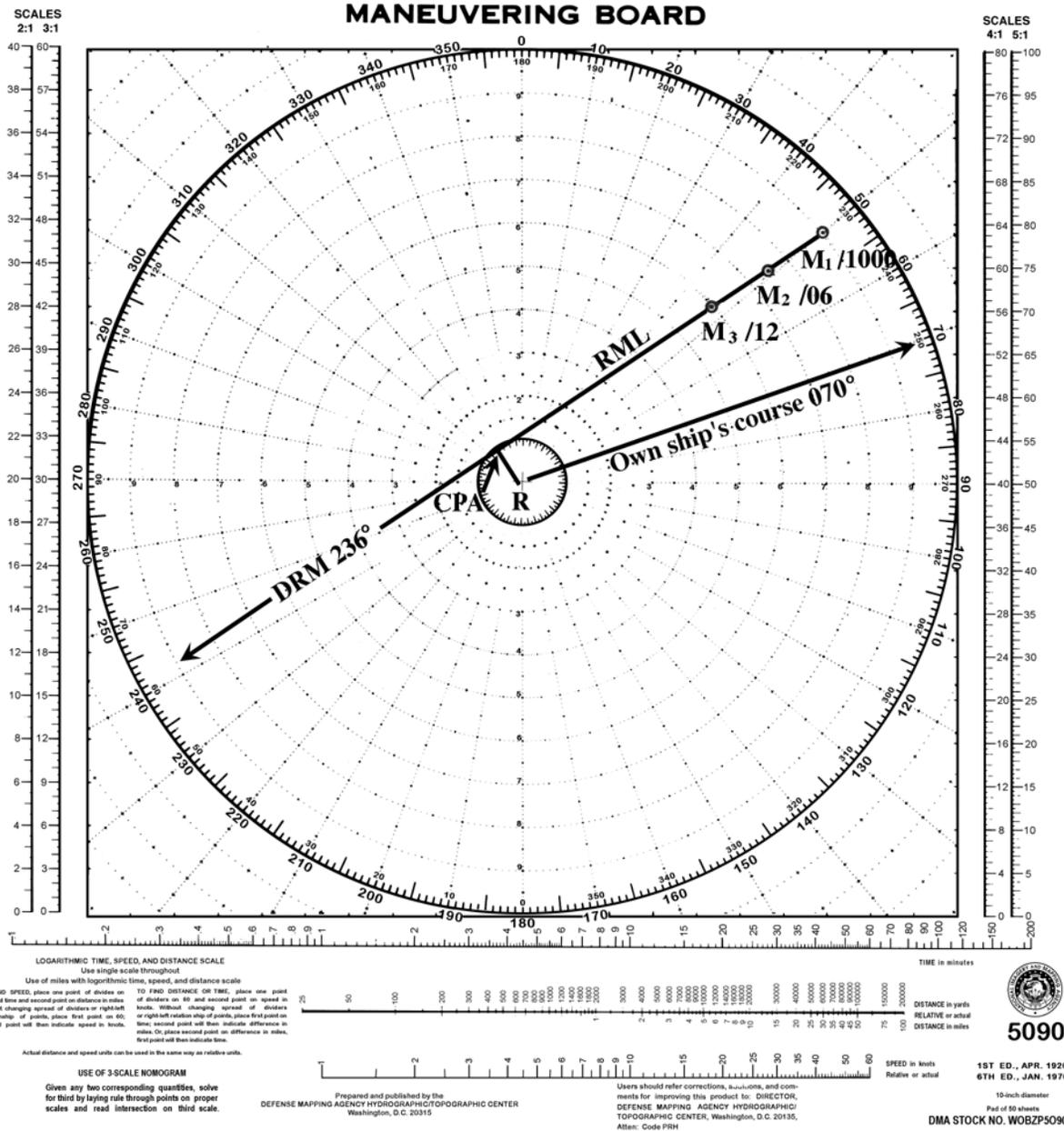
(4) From the center of the radar plotting sheet, R, draw a line perpendicular to the RML; label the intersection CPA. The direction of the CPA from the center of the plotting sheet, i.e., own ship's position, is the bearing of the CPA: 326°; the distance from the center or own ship is the range at CPA: 0.9 mile.

(5) Measure the distance from M₃ to CPA: 6.0 miles. Using this distance and the speed of relative movement (SRM): 15 knots, obtain the time interval from 1012 (the time of plot M₃) by means of the Time-Speed-Distance Scale: 24^m. The estimated time of arrival at CPA is 1012 + 24^m = 1036.

Answers:

- (1) DRM 236°; (2) SRM 15 knots; (3) CPA 326°, 0.9 mile; (4) ETA at CPA 1036.

EXAMPLE 1



Notes:

1. There should be sufficient plots to insure accurate construction of the RML faired through the plots. Should only two plots be made, there would be no means of detecting course or speed changes by the other ship. The solution is valid only if the other ship maintains course and speed constant. Preferably, the timed plots should be made at equal time intervals. Equal spacing of the plots timed at regular intervals and the successive plotting of the relative positions in a straight line indicate that the other ship is maintaining constant course and speed.

2. This transfer plotting solution required individual measurements and recording of the ranges and bearings of the relative position of ship M at intervals of time. It also entailed the normal requirement of plotting the relative positions on the PPI or reflection plotter. Visualizing the concentric circles of the Maneuvering Board as the fixed range rings of the PPI, a faster solution may be obtained by fairing a line through the grease pencil plot on the PPI and adjusting the VRM so that the circle described is tangent to or just touches the RML. The range at CPA is the setting of the VRM; the bearing at CPA and the DRM may be found by use of the parallel-line cursor (parallel index). The time of the CPA can be determined with reasonable accuracy through visual inspection, i.e., the length along the RML from M_3 to CPA by quick visual inspection is about twice the length between M_1 and M_3 representing about 24 minutes.

EXAMPLE 2

COURSE AND SPEED OF A RADAR CONTACT

Situation:

Own ship R is on course 340° , speed 15 knots. The radar is set on the 12-mile range scale. A radar contact, ship M, is observed to be changing course, and possibly speed, between times 0953 and 1000. While keeping a close watch of the relative movement, the relative positions of M are marked at frequent intervals on the reflection plotter by grease pencil.

Required:

- (1) Course and speed of ship M when M has steadied on course and speed.

Solution:

(1) With the decision made that the solution will be obtained by rapid radar plotting, the solution is started while M is still maneuvering through determining: (a) the distance own ship will travel through the water during a time lapse of 6 minutes and (b) the length of such distance on the PPI at the range setting in use.

(i) The distance traveled by own ship in 6 minutes is one-tenth of the speed in knots, or 1.5 nautical miles.

(ii) The length of 1.5 nautical miles on the PPI may be found through use of the variable range marker (VRM). Crank the VRM out to a convenient starting point, 6 miles for instance.

Mark the intersection of the VRM and the heading flash. Crank the VRM

out to 7.5 miles and mark the intersection of the VRM and the heading flash. The length between the two marks (1.5 mi.) is transferred to a short plastic rule.

(2) Observation of the PPI reveals that between 1000 and 1006, M is on a steady course at constant speed (successive plots form a straight line on the scope; plots for equal time intervals are equally spaced). Draw the relative movement line (RML) from the 1000 plot (M_1) through the 1006 plot (M_3), extending beyond the center of the PPI.

(3) Set center line of parallel-line cursor to heading flash. At the 1000 plot (M_1) place the plastic rule, marked for the 6-minute run of own ship, parallel to the cursor lines. In the *direction of own ship's course*, draw a line of 1.5 miles length which ends at the 1000 plot. Two sides of the vector triangle have been formed (*er* and *rm*). The solution is obtained by completing the triangle to form true (course-speed) vector *em*.

(4) On completing the triangle, the third side, vector *em*, represents the true course and rate of movement of M. The true course may be read by adjusting the parallel-line cursor parallel to the third side, true vector *em*. The speed of M in knots may be estimated by comparing the length of *em* with the length of *er*, the true (course-speed) vector of own ship R, the speed of which in knots is known.

Answers:

- (1) Course 252° , speed 25 knots.

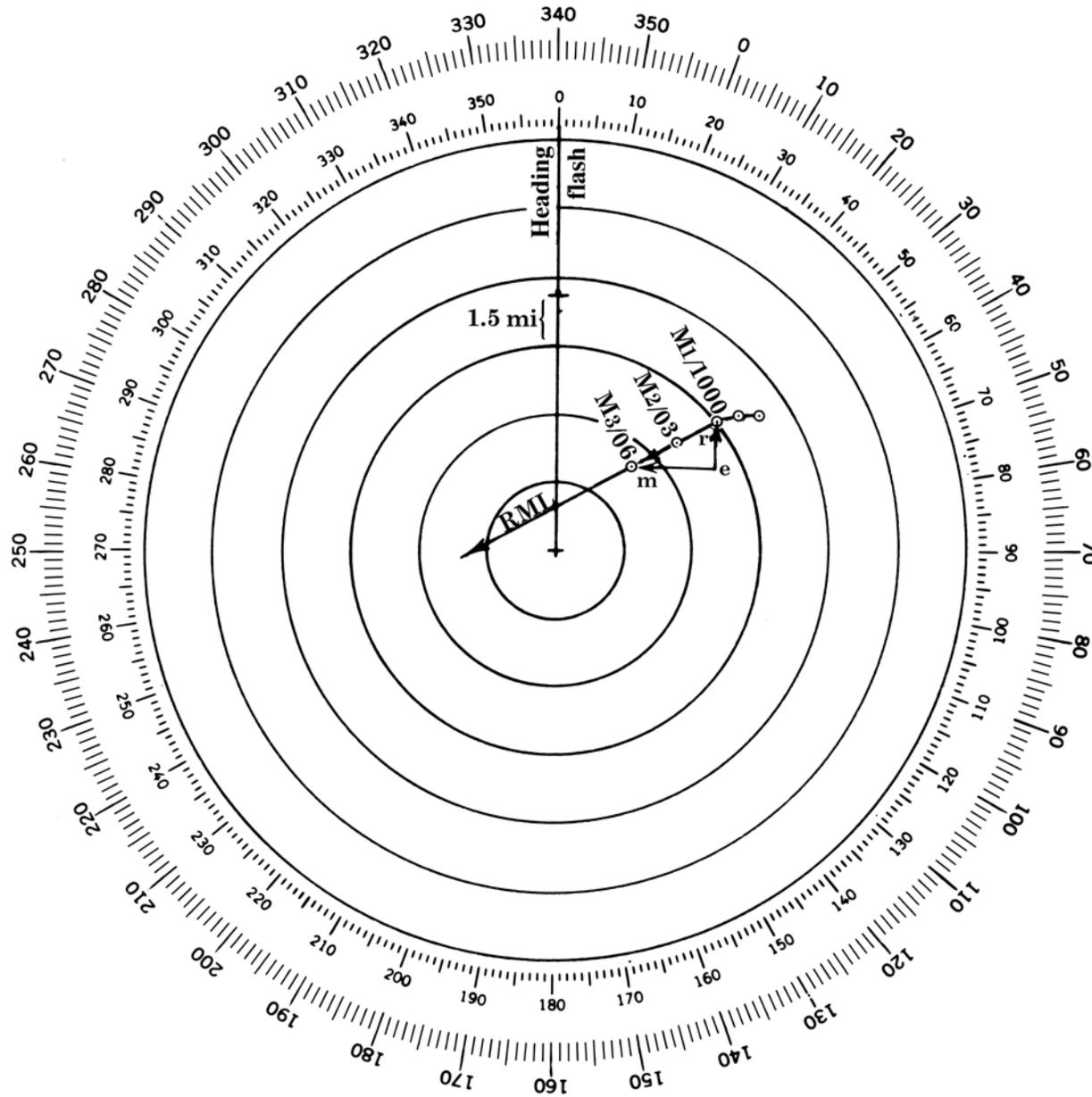
EXAMPLE 2

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Note:

In some cases it may be desirable to construct own ship's true vector originating at the end of the segment of the relative plot used directly as the relative vector rm . If applied to this case, the 6-minute run of own ship would be drawn from the 1006 plot in the direction of own ship's course. On completing the triangle, the third side would represent the true course and rate of movement of M.



EXAMPLE 3

COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD

Situation:

Own ship R is on course 120°, speed 15 knots. The radar is set on the 6-mile range scale because small wooden vessels are expected to be encountered. The range scale setting is being shifted periodically to longer ranges for possible detection of distant targets. A radar contact is being plotted on the reflection plotter. Inspection of the plot reveals that the contact is on steady course at constant speed (see solution step (2) of example 2).

Required:

- (1) Course and speed of the radar contact.

Solution:

(1) With the decision made that the solutions will be obtained by rapid radar plotting, the radar observer further elects to use the Ladder Method in order to be able to *refine* the solution as the relative plot for the contact develops with time.

(2) For a 6-minute interval of time, own ship at 15 knots runs 1.5 nautical miles through the water; the run for 12 minutes is 3.0 nautical miles.

(3) Draw own ship's true (course-speed) vector *er* in the direction of own ship's true course, with the head of the vector at the 0506 plot; the length of this vector is drawn in multiples of 6-minute runs of own ship and subsequently subdivided by eye to form a ladder. Since the *timed* plot on the relative movement line starts at 0506, the starting point of the 6-minute run of own ship is labeled 12; the starting point of the 12-minute run is labeled 18.

(4) The first solution is obtained at time 0512 by drawing a line from the 12-graduation or rung on the ladder to the 0512 plot on the RML. This line, which completes the vector triangle for a 6-minute run, represents the true course and rate of movement of the contact. The true course and speed of the contact is obtained as in solution step (4) of Example 2.

(5) The second solution is obtained at time 0515 by drawing a line from the 15-graduation or rung on the ladder to the 0515 plot on the RML. This line, which completes the vector triangle for a 9-minute run, represents the true course and rate of movement of the contact.

Answers:

- (1) Course 072°, Speed 17 knots.

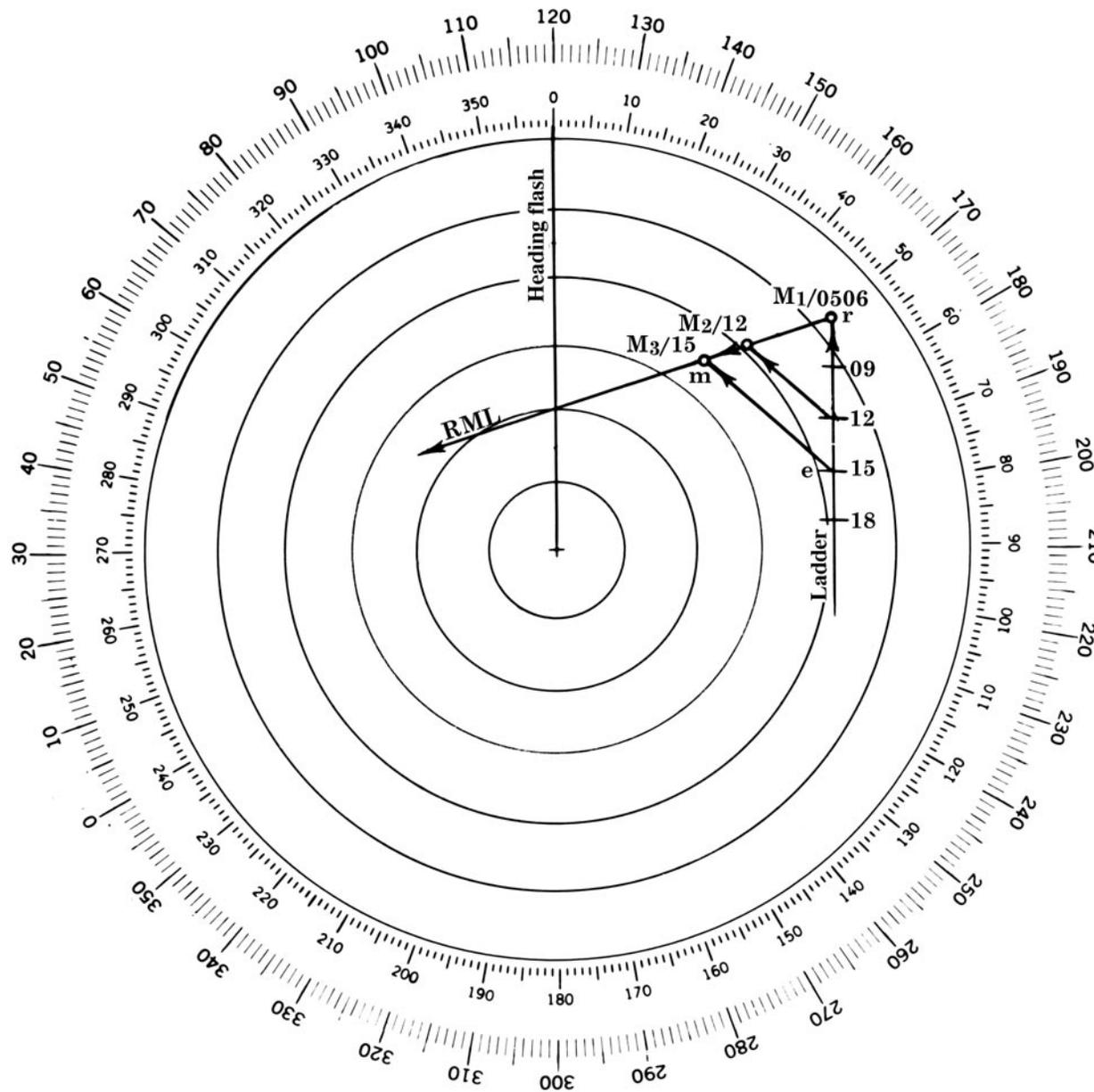
EXAMPLE 3

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 6-mile range setting

Notes:

1. Using the ladder method, the radar observer is able to obtain an approximate solution quickly and then refine the solution as the plot develops.
2. This solution was simplified by starting the timed plot at some tenth of an hour after the hour.



EXAMPLE 4

COURSE TO PASS A SHIP AT A SPECIFIED CPA (Own ship's speed is greater than that of other ship)

Situation:

Own ship R is on course 188° , speed 18 knots. The radar is set on the 12-mile range scale. Other ship M, having been observed and plotted between times 1730 and 1736, is on course 258° at 12 knots. Ships M and R are on collision courses. Visibility is 2.0 nautical miles.

Required:

(1) Course of own ship R at 18 knots to pass ahead of other ship M with a CPA of 3.0 nautical miles if course is changed to the right when the range is 6.5 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course and speed of other ship M, plot M_x bearing 153° , 6.5 nautical miles from R. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x draw a line tangent to the VRM circle at M_3 . From M_x two lines can be drawn tangent to the circle, but the point of tangency at M_3 fulfills the requirement that own ship pass ahead of the other ship or that other ship M pass astern of own ship R.

(2) From the origin of the true vectors of the vector triangle used in finding the true course and speed of ship M, point e , describe an arc of radius 1.8 nautical miles. Since own ship R will not change speed in the maneuver, the distance and corresponding PPI length of own ship's true vector (1.8

nautical miles for a 6-minute run of own ship at 18 knots) is used as the radius of the arc.

(3) Using the parallel-line cursor, draw a line through M_2 parallel to the new RML ($M_x M_3$) to intersect the arc drawn in (2).

(4) The intersection of the arc with the line through M_2 parallel to the new RML establishes the head of the own ship's new true (course-speed) vector drawn from point e . Therefore, own ship's new course when other ship M reaches relative position M_x is represented by the true vector drawn from point e to the intersection at r_1 .

Answers:

(1) Course 218° .

Notes:

1. Actually the arc intersecting the line drawn M_2 in a direction opposite to the new DRM would also intersect the same line if extended in the new DRM. But a new course of own ship based upon this intersection would reverse the new DRM or reverse the direction the other ship would plot on the new RML.

2. If the speed of other ship M were greater than own ship R, there would be two courses available at 18 knots to produce the desired distance at CPA. Generally, the preferred course is that which results in the highest relative speed in order to expedite the safe passing.

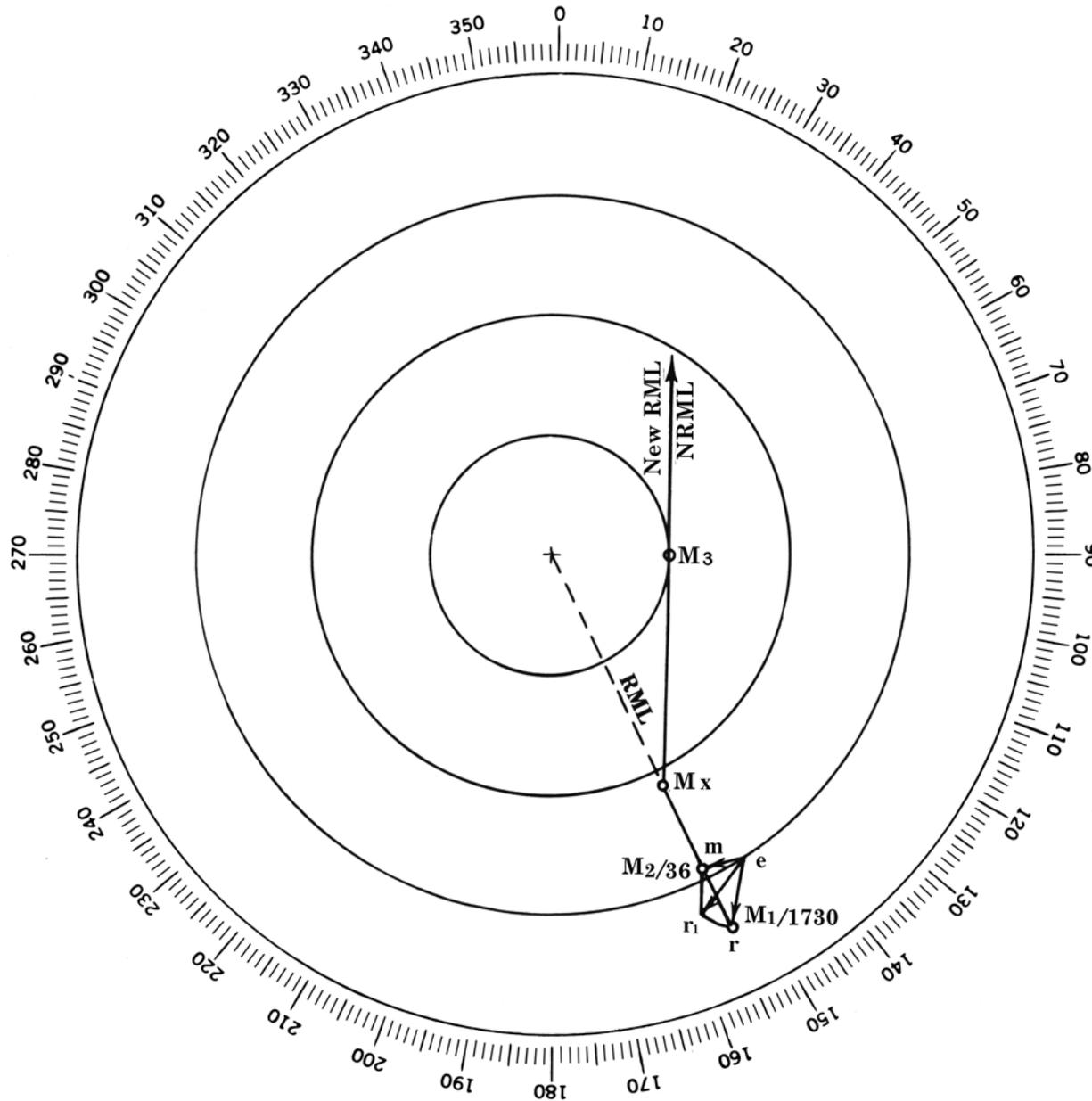
EXAMPLE 4

North-Upward Stabilized PPI Display

Scale: 12-mile range setting

Notes: (Continued)

3. After own ship's course has been changed, other ship R should plot approximately along the new RML, as drawn and in the desired direction of relative movement. This continuity of the plot following a course change by own ship is one of the primary advantages of a stabilized display. Immediately following any evasive action, one should inspect the PPI to determine whether the target's bearing is changing sufficiently and in the desired direction. With the stabilized display, the answer is before the radar observer's eyes.



EXAMPLE 5

COURSE TO PASS SHIP AT A SPECIFIED CPA (Own ship's speed is less than that of other ship)

Situation:

Own ship R is on course 340° , speed 15 knots. The radar is set on the 12-mile range scale. Other ship M, having been observed and plotted between times 0300 and 0306, is on course 249° at 25 knots. Since the CPA will be 1.5 nautical miles at 310° if both ships maintain their courses and speeds until they have passed, the distance at CPA is considered too short for adequate safety.

Required:

(1) Course of own ship R at 15 knots to pass astern of other ship M with a CPA of 3.0 nautical miles if course is changed to the right when the range to ship M is 6.0 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course, speed, and CPA of ship M, plot M_x on the RML 6.0 nautical miles from own ship R. Set the VRM to 3.0 nautical miles, the desired distance at CPA (in this case the VRM setting is coincident with the first fixed range ring). From M_x two lines can be drawn tangent to the VRM circle, but the point of tangency at M_3 fulfills the requirement that own ship pass astern of other ship M.

(2) From the origin of the true vectors of the vector triangle used in finding the true course and speed of ship M, point e , describe an arc of radius 1.5 nautical miles. Since own ship will not change speed in the maneuver, the distance and corresponding PPI length of own ship's true vector (1.5

nautical miles for a 6-minute run of own ship at 15 knots) is used as the radius of the arc.

(3) Using the parallel-line cursor, draw a line through M_2 parallel to the new RML ($M_x M_3$) to intersect the arc drawn in (2).

(4) Since the speed of other ship M is greater than that of own ship R, the arc intersects the line through M_2 at two points. Each intersection establishes a head of a possible new own ship's true vector. Of the two possible vectors one provides a higher speed of relative movement than the other. Generally, the true vector which provides the higher SRM or longer relative vector is chosen to expedite the passing. However, in this example a course change to the right is specified. This requires the use of vector er_1 , which provides the higher SRM.

(5) With this unstabilized, Heading-Upward PPI display, there is a complication arising from the plot shifting equal and opposite to the amount and direction of the course change. Some reflection plotter designs have provisions for either manual or automatic shifting of their plotting surfaces to compensate for the shifting of the plot. Without this capability, there is no continuity in the grease pencil plot following course changes by own ship. Consequently, it is necessary to erase the plot and replot the other ship's relative position when own ship steadies on course. With the VRM set to 3.0 miles, the new RML must be drawn tangent to the circle described by the VRM. The other ship must be watched closely to insure that its relative movement conforms with the new RML.

Answers:

(1) Course 030° .

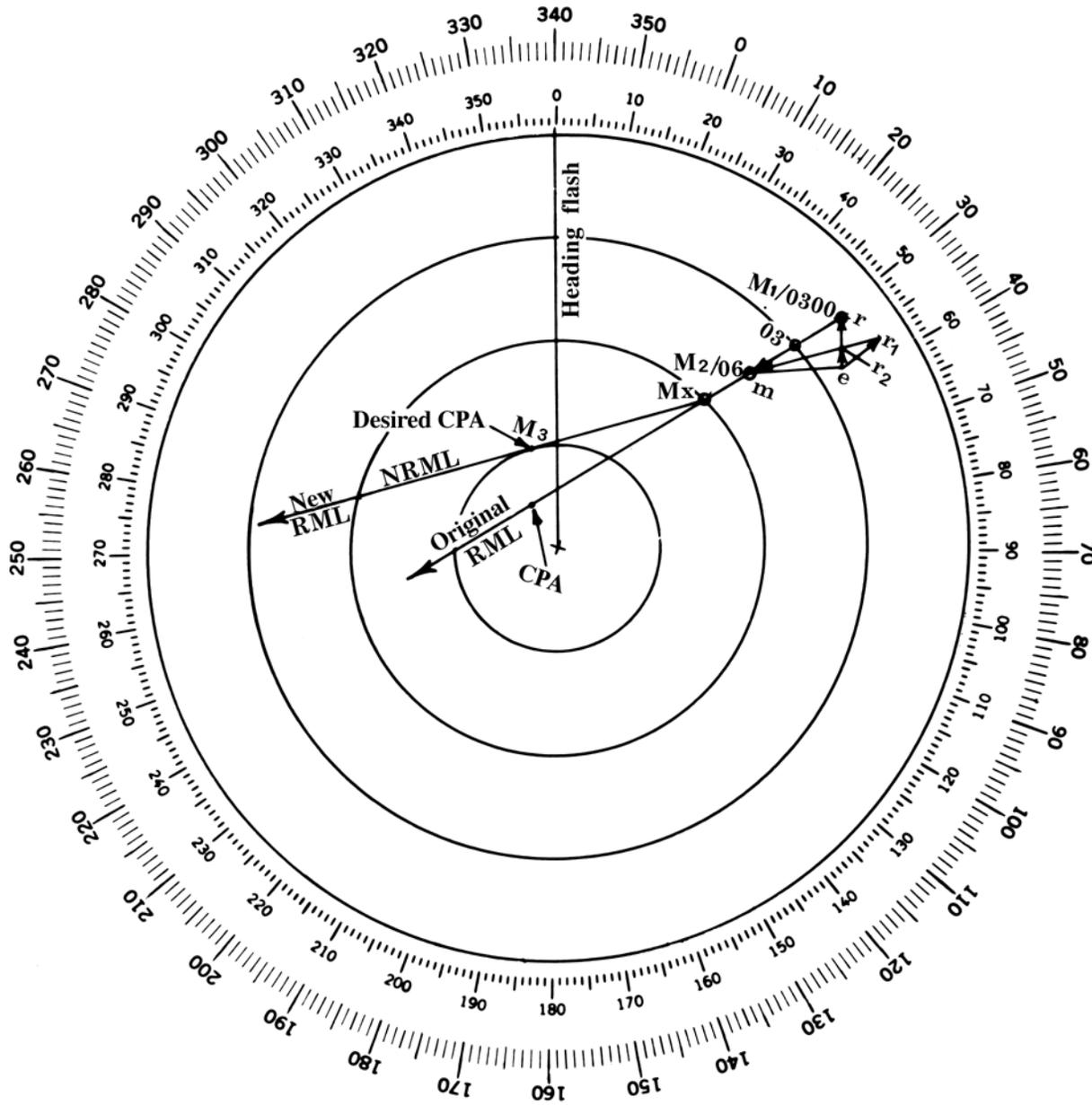
EXAMPLE 5

**Heading-Upward
Unstabilized PPI Display
with Stabilized True
Bearing Dial**

Scale: 12-mile range setting

Note:

Examination of the plot reveals that if own ship R maintains its original true course (340°), the intersection of the original true vector er of own ship with the line drawn through M_2 parallel to the new RML provides the head of the vector er_2 required to effect the desired CPA without course change. Since the length of vector er_2 is approximately half that of the original vector er , an instantaneous change to approximately half the original speed would produce the desired results. A lesser change of course to the right in conjunction with a speed reduction could be used to compensate for deceleration.



EXAMPLE 6

VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER

Situation:

Own ship R is on course 340° , speed 20 knots. The radar is set at the 24-mile range scale. Radar observations are made as follows:

<i>Time</i>	<i>Bearing</i>	<i>Range (miles)</i>	<i>Rel. position</i>
1200	017°	22.8	M_1
1218	029°	17.4	M_2
1236	046°	14.4	M_3

The RML is parallel to and the DRM is opposite to own ship's course, 340° .

Required:

Course and speed of M in order to verify whether M is dead in the water or a terrestrial object.

Solution:

(1) On the PPI, preferably a reflection plotter mounted thereon, plot M_1 , M_2 , M_3 . Draw the relative movement line (RML) through the relative positions, M_1 , M_2 , M_3 .

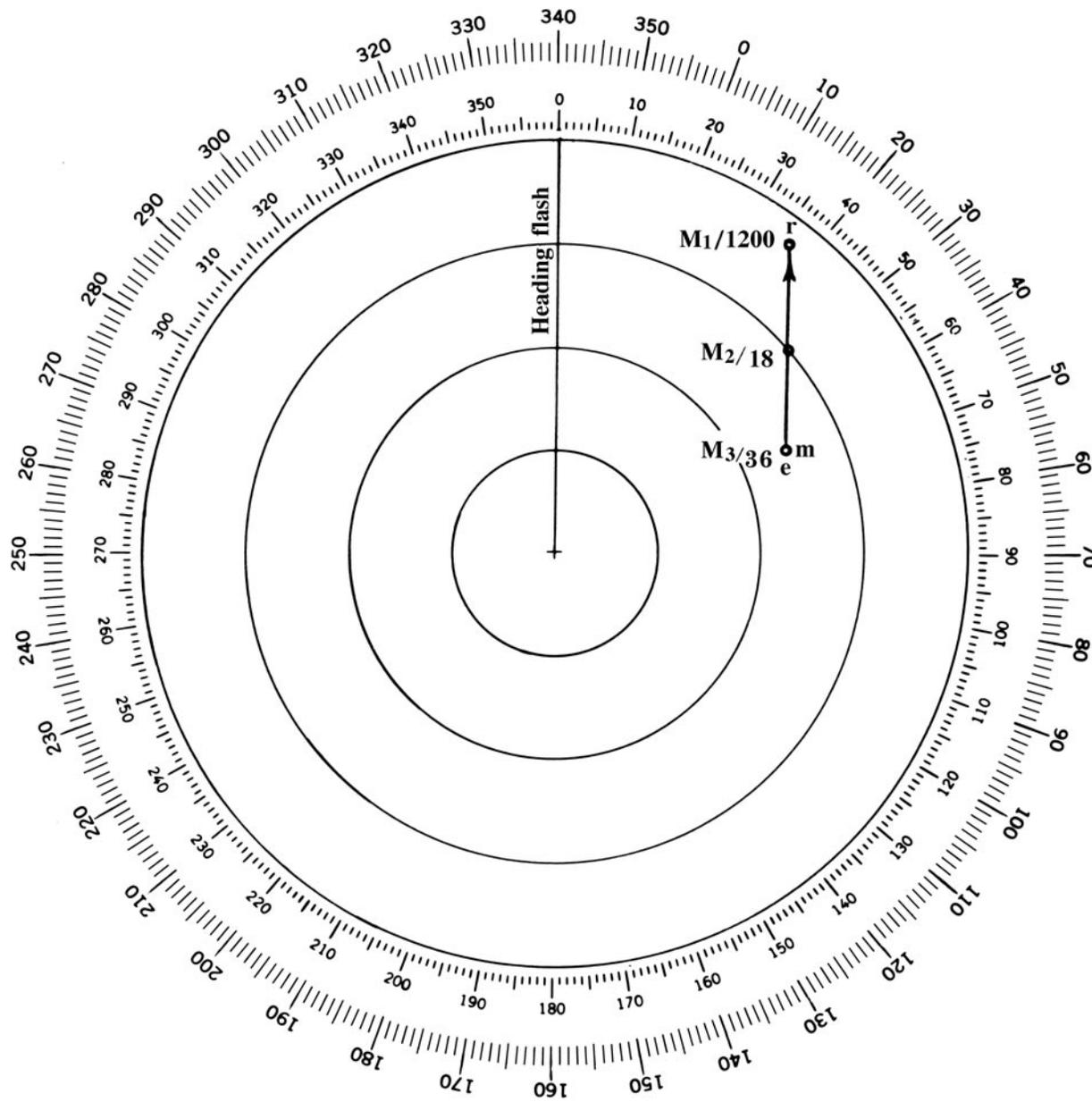
(2) Using the same distance scale as the radar range setting, determine the length of the true (course-speed) vector er of own ship R for a time interval of 36 minutes: 12 miles.

(3) Draw true vector er in the direction of own ship's course with its head at relative position M_1 . If, after such graphical construction, the vector origin e lies over relative position M_3 , the length of the em vector would be zero. Thus, the true speed of the observed contact would be zero. Even if the observed target is dead in the water or a fixed object, small observational and plotting errors will frequently indicate a small value of true speed for the contact.

EXAMPLE 6

Heading-Upward
Unstabilized PPI Display
with Stabilized True
Bearing Dial

Scale: 24-mile range setting



EXAMPLE 7

AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING THE TRUE COURSES AND SPEEDS OF THE CONTACTS

Situation:

Own ship R is on course 000° , speed 20 knots. With the stabilized relative motion display radar set at the 12-mile range setting, radar contacts A, B, and C are observed and plotted directly on the PPI or reflection plotter. The plots at time 1000 are considered as the initial plots in the solution.

Required:

(1) Determine the new relative movement lines for contacts A, B, and C which would result from own ship changing course to 065° and speed to 15 knots at time 1006.

(2) Determine whether such course and speed change will result in desirable or acceptable CPA's for all contacts.

Solution:

(1) With the center of the PPI as their origin, draw own ship's true vectors er and er' for the course and speed in effect or to be put in effect at times 1000 and 1006, respectively. Using the distance scale of the radar presentation, draw each vector of length equal to the distance own ship R will travel through the water during the time interval of the relative plot (relative vector), 6 minutes. Vector er , having a speed of 20 knots, is drawn 2.0 miles in length in true direction 000° ; vector er' , having a speed of 15 knots, is drawn 1.5 miles in length in true direction 065° .

(2) Draw a dashed line between r and r' .

(3) For contacts A, B, and C, offset the initial plots (A_1 , B_1 , and C_1) in the same direction and distance as the dashed line $r-r'$; label each such offset plot r' .

(4) In each relative plot, draw a straight line from the offset initial plot, r' , through the final plot (A_2 or B_2 or C_2). The lines $r' A_2$, $r' B_2$, and $r' C_2$ represent the new RML's which would result from a course change to 065° and speed change to 15 knots at time 1006.

Answers:

- (1) New RML of contact A-DRM 280°
New RML of contact B-DRM 051°
New RML of contact C-DRM 028°

(2) Inspection of the new relative movement lines for all contacts indicates that if all contacts maintain course and speed, all contacts will plot along their respective relative movement lines at a safe distances from own ship R on course 065° , speed 15 knots.

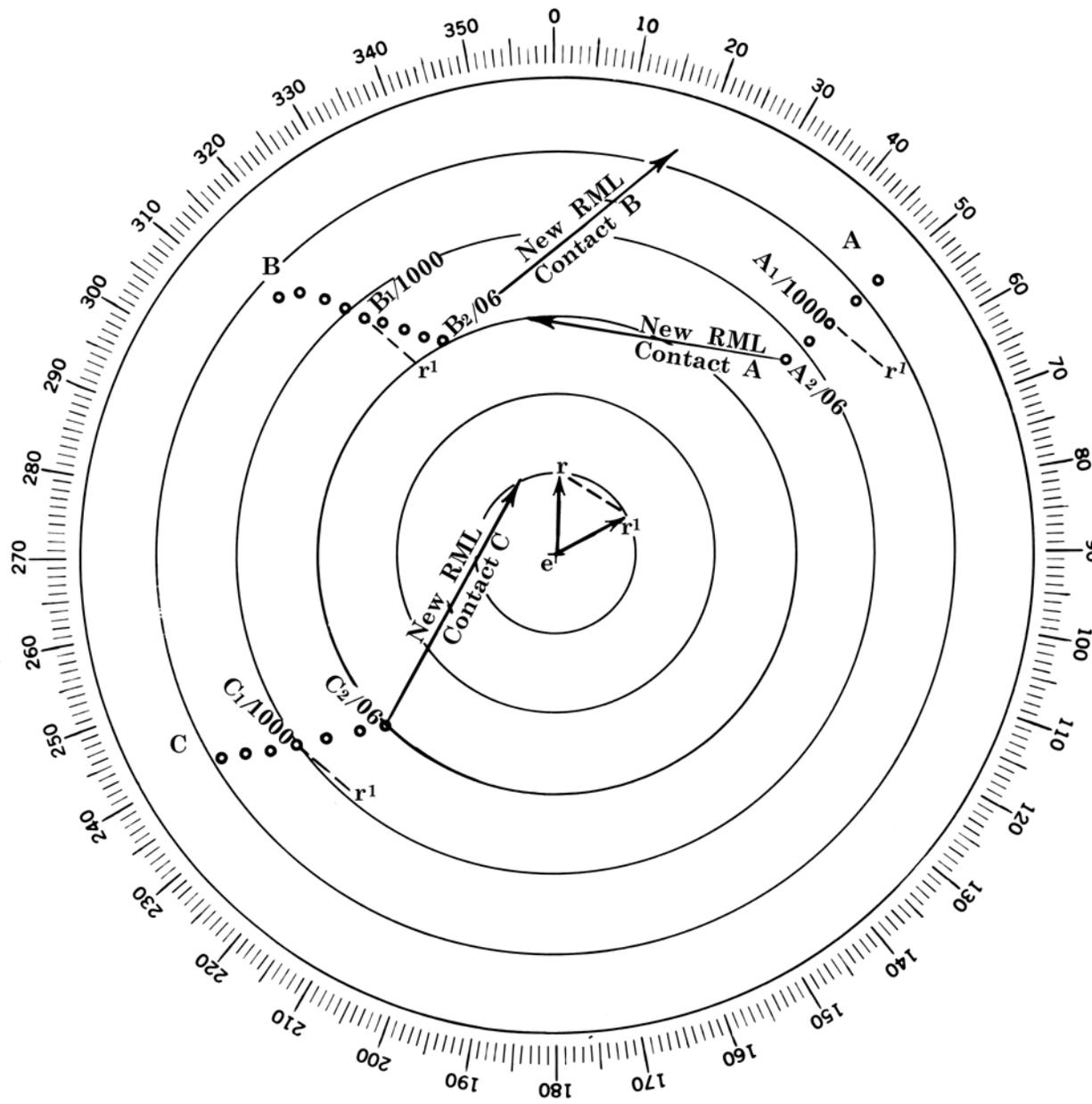
Explanation:

The solution is based upon the use of the relative plot as the relative vector. With each contact maintaining true course and speed, the em vector for each contact remains static while own ship's er' vector is rotated about e to the new course and changed in magnitude corresponding to the new speed.

EXAMPLE 7

North-Upward
Stabilized PPI Display

Scale: 12-mile range setting



EXAMPLE 8

DETERMINING THE CLOSEST POINT OF APPROACH FROM THE GEOGRAPHICAL PLOT

Situation:

Own ship R is on course 000°, speed 10 knots. The true bearings and ranges of another ship are plotted from own ship's successive positions to form a geographical (navigational) plot:

<i>Time</i>	<i>Bearing</i>	<i>Range (miles)</i>	<i>Rel. position</i>
0200	074°	7.3	T ₁
0206	071°	6.3	T ₂
0212	067°	5.3	T ₃

Required:

- (1) Determine the closest point of approach.

Solution:

- (1) Since the successive *timed* positions of each ship of the geographical

plot indicate rate of movement and true direction of travel for each ship, each line segment between successive plots represents a true velocity vector. Equal spacing of the plots timed at regular intervals and the successive plotting of the true positions in a straight line indicate that the other ship is maintaining constant course and speed.

(2) The solution is essentially a reversal of the procedure in relative motion solutions in which, from the relative plot and own ship's true vector, the true vector of the other ship is determined. Accordingly, the true vectors from the two true plots for the same time interval, 0206-0212 for example, are subtracted to obtain the relative vector ($rm = em - er$).

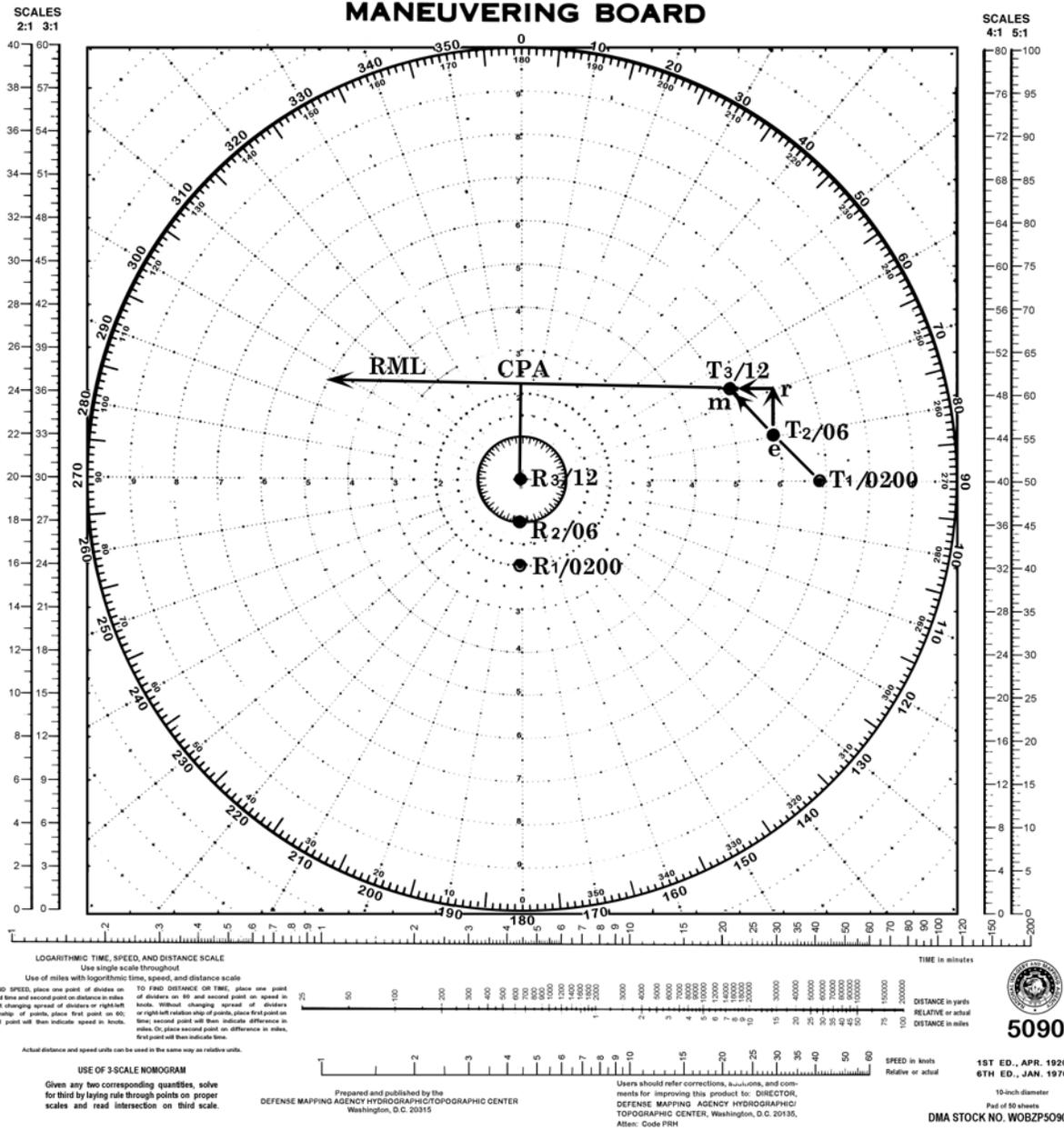
(3) The relative (DRM-SRM) vector rm is extended beyond own ship's 0212 position to form the relative movement line (RML).

(4) The closest point of approach (CPA) is found by drawing a line from own ship's 0212 plot perpendicular to the relative movement line.

Answers:

- (1) CPA 001°, 2.2 miles.

EXAMPLE 8



Note:

Either the time 0200, 0206, or 0212 plots of the other ship can be used as the origin of the true vectors of the vector diagram. Using the time 0200 plot as the origin and a time interval of 6 minutes for vector magnitude, the line perpendicular to the extended relative movement line would be drawn from the time 0206 plot of own ship.

While the Maneuvering Board has been used in illustrating the solution, the technique is applicable to solutions for CPA on true motion displays. See PRACTICAL SOLUTION FOR CPA IN TRUE MOTION MODE.

ALTERNATIVE RADAR PLOTTING SYMBOLS

The alternative radar plotting symbols described in this section were derived from those used in *Real Time Method of Radar Plotting* by Max H. Carpenter and Captain Wayne M. Waldo of the Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland. The above manual should be referred to for a more complete explanation of the symbols and their use in radar plotting.

The explanation of the alternative symbols as given here follows an approach different from that used by Carpenter and Waldo. The two approaches should be helpful to the student.

The alternative symbols are deemed to provide simpler and more representational symbology for Rapid Radar Plotting than does the *Maneuvering Board* symbology, which has value for relative motion solutions of greater variety than those normally associated with collision avoidance. Greater simplicity is afforded by using the same symbols for the relative motion plot and the corresponding side of the vector diagram (triangle). The symbols are deemed to be more representational in that the symbols suggest their meaning.

As shown in figure 3.36, the relative motion plot is labeled *R-M*; the true motion plot is labeled *T-M*. In the relative motion case, the first plot is at *R*; the second plot (or the plot for the time interval to be used in the solution) is labeled *M*. Thus, *R-M* is descriptive of the relative motion plotted. Likewise with the first plot being labeled *T* in the true motion case, *T-M* is descriptive of the true motion plotted.

As is also shown in figure 3.36, the plots are annotated with time in two digits (for minutes of time). Preferably the first plot is for zero time rather than clock time. Such practice is enhanced with the use of a suitable timer which can be readily reset as required. Such practice, which is followed here, facilitates plotting at desired intervals and also enables more accurate timing of the plot.

When using this symbology in textual references, time interval from zero time is indicated as a subscript of a symbol when appropriate. For example, the relative plot (or relative vector) for plotting interval 3 minutes may be shown as

$$R_{00}—M_{03}$$

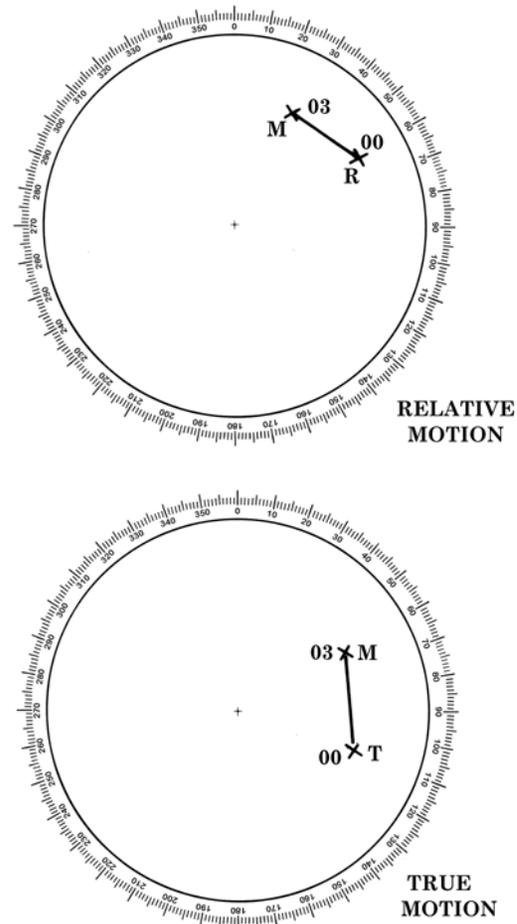


Figure 3.36 - Relative and true motion plots.

In actual plotting on the reflection plotter, the placement of the time annotation is affected by practical considerations, including clutter.

With consideration at this point that Rapid Radar Plotting makes direct use of the relative plot as the relative vector of the vector diagram (triangle), the symbols for the other two vectors or sides of the triangle are now described.

Since the other two vectors are *true* vectors, the symbol *T* is used to indicate the origin of both vectors at a common point. One of the true vectors must end at *R*, the other at *M*. The true vector *T-R* is own ship's (reference ship *R* in the other symbology) true (course-speed) vector; the other true vector *T-M* is the other ship's (other ship *M* in the other symbology) true (course-speed) vector.

Own ship's true vector *T-R* being suggestive of the abbreviation *TR* for track, in turn suggests true course and speed. Or, using a combination of symbologies, the symbol *T-R* suggests true vector for reference ship *R* (own ship).

The other ship's true vector *T-M* is suggestive of true motion (of the other ship, or of other ship *M*, using a combination of symbologies). See figure 3.37 for the *R-T-M* triangle.

Now thinking in terms of true motion rather than true course and speed of the other ship, the abbreviations *DTM* and *STM* are used to indicate direction of true motion and speed of true motion, respectively.

In brief the vectors are comprised of the following elements:

R-M: DRM & SRM

T-R: Course & Speed (of own ship)

T-M: DTM & STM (of other ship)

Abbreviations common to both symbologies are CPA (Closest Point Approach), DRM (Direction of Relative Movement), SRM (Speed of Relative Movement) and NRML (New Relative Movement Line). In addition to DTM (Direction of Contact's True Motion) and STM (Speed of Contact's True Motion), the alternative symbology uses MCPA for minutes to CPA. The symbol *R* is used to indicate the head of own ship's true vector following a change of course or speed or both to obtain a new RML. The symbol *M* is also used to indicate the point of execution.

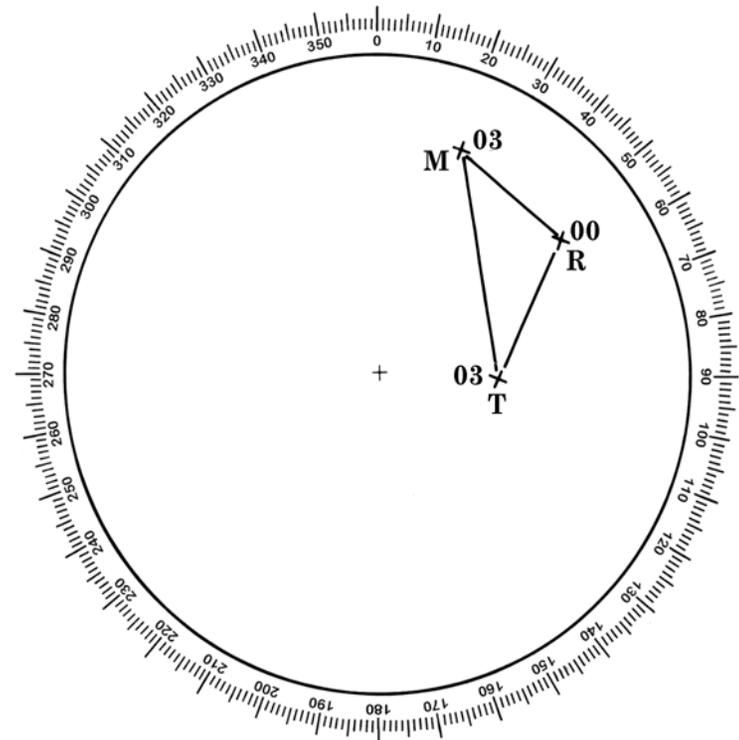


Figure 3.37 - *R-T-M* triangle.

The following is an alternative presentation of the R - T - M triangle which does not use vector terminology.

By examining the combination geographic (true) and relative plot in figure 3.38, it can be seen that T - M of the triangle is the path actually followed by the other ship at the rate of its actual speed. At the time of the first observation from T' , the other ship was actually at T , not R . Also own ship was at T' , not R' . However, at the end of the plotting interval, the other ship was actually at M and own ship was actually at R' . But all observations of the other ship were actually plotted from R' . Thus, the first observation placed the other ship at R ; successive observations place the other ship at points along R - M until M was reached at the end of the plotting interval.

In the above presentation the true motion of the other ship is given. But in the normal course of radar observation for collision avoidance purposes, this motion must be determined. With R - M derived by plotting, it can be seen by inspection that T of the triangle can be located by constructing T - R in the direction of own ship's course and scaled according to the distance own ship travels during the plotting interval. After such construction, the triangle is completed to find T - M (DTM & STM).

STANDARD PLOTTING PERIOD

A standard plotting period, which varies in a simple, easily remembered relationship with the range scale setting, can be used to facilitate scaling T - R or determining STM from T - M . The use of standard plotting period is enhanced when the PPI has six fixed range rings and the range scales are $1\frac{1}{2}$, 3, 6, 12, 24, and 48 miles.

The standard plotting period enables the direct use of the range ring separation as the speed scale as shown below. On a given properly adjusted (for linearity) PPI with six range rings, the ring separation is 5 centimeters. On the 6-mile scale, this separation (5 centimeters) represents 1 nautical mile. On the 12-mile scale, the same separation between rings (5 centimeters) represents 2 nautical miles; and on the 24-mile scale, 4 nautical miles, etc. With distance in miles traveled in 6 minutes being numerically equal to one-tenth of the speed in knots, at 20 knots a vessel travels 2 miles in 6 minutes. Thus, on the frequently used 12-mile scale, a vessel steaming at 20 knots (relative or true) travels a distance (relative or true) equal to the range ring separation (5 centimeters or 2 nautical miles) in the number of minutes (6) equal to one half of the range scale in miles (12). With the range scale changed to 6 miles, a vessel at 20 knots (relative or true) still travels a distance (relative or true) equal to the range ring separation (5 centimeters

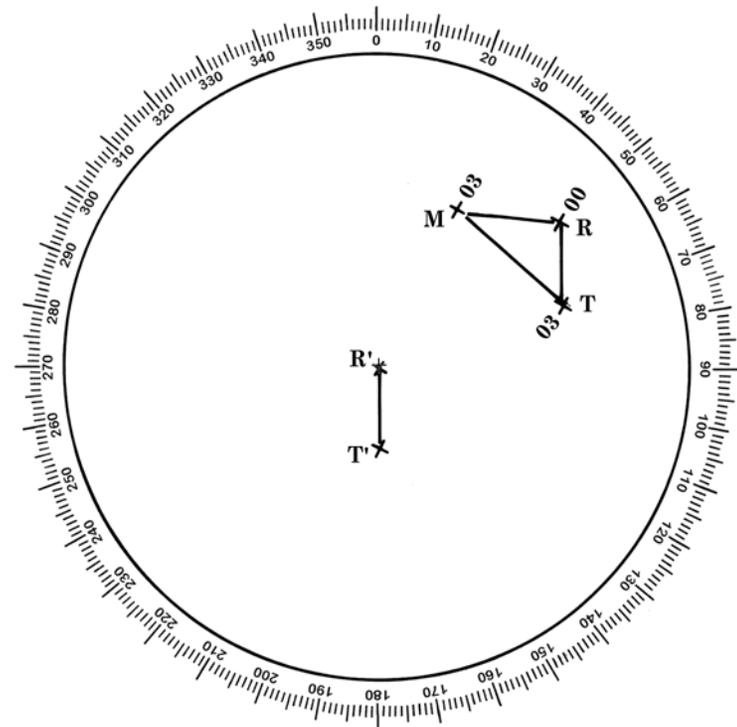


Figure 3.38 - Combination geographic (true) and relative plot.

now corresponding to 1 nautical mile) during the number of minutes (3) equal to one half of the range scale in miles (6).

Whatever the speed of own ship or of the other ship may be, for the six-ring PPI having the scales as described above, the standard plotting period remains: a period in minutes equal to one half of the range scale in miles. For example on the 12-mile scale and using the associated 6-minute standard plotting period, a vessel at 20 knots travels one ring separation (5 centimeters) during the plotting period; at 10 knots the vessel travels one half of the ring separation during the same period. Thus a single speed scale can be calibrated linearly for use with different range scales. But the associated standard plotting period must be used with each range scale.

In summary, the standard plotting period makes one range ring separation equal to 20 knots whatever the range scale setting may be. Multiples and sub-multiples of this one range ring separation for 20 knots establish other speeds as shown in figure 3.39.

The standard plotting intervals based upon the six-ring PPI and range scales described above and upon one range ring separation corresponding to 20 knots are summarized as follows:

<i>Range Scale (miles)</i>	<i>Standard Plotting Period</i>
12	6 min.
6	3 min.
3	90 sec.
1.5	45 sec.

If the PPI has four fixed range rings, standard plotting periods can be established in like manner for one range ring separation equal to 20 knots. As with the six-ring PPI, the standard plotting period doubles as the range scale doubles. The only difference is that the standard plotting period is three-fourths of the range scale setting, instead of one-half.

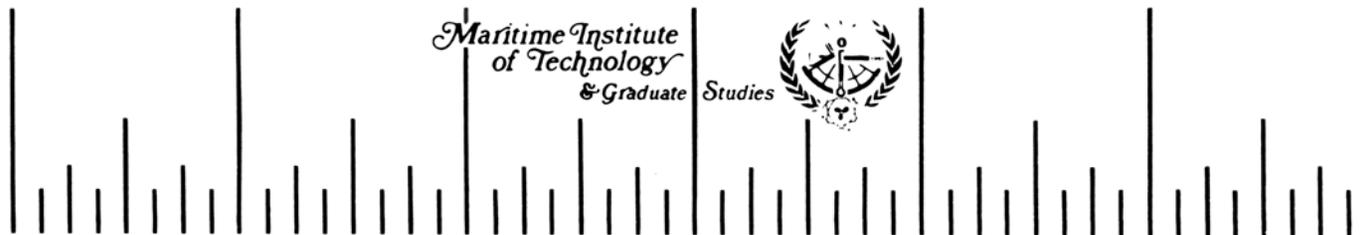


Figure 3.39 - Standard plotting period scale. Under "black light" illumination a plastic scale of chartreuse color has been found to be most useful.

SUMMARY OF ALTERNATIVE PLOTTING SYMBOLS
R-T-M TRIANGLE

RELATIVE PLOT		VECTOR TRIANGLE	
Symbol	Meaning	Symbol	Meaning
R_{00}	First plotted position of other ship; plotted position of other ship at time 00.	T_{03}	The origin of any ship's true (course-speed) vector; fixed with respect to the earth. The subscript is the plotting period used to construct the triangle.
M_{03}, M_{06}	Plotted positions of other ship at times 03 and 06, respectively.	R_{00}	The head of own ship's true (course-speed) vector, $T_{03}-R_{00}$; the origin of the relative (DRM-SRM) vector, $R_{00}-M_{03}$.
M_x	Position of other ship on RML at planned time of evasive action; point of execution.	$T_{03}-R_{00}$	Own ship's true (course-speed) vector.
RML	Relative movement line.	$T_{03}-M_{03}$	Other ship's true (course-speed) vector. The subscript is the plotting period used to construct the triangle.
NRML	New relative movement line.	DTM	Direction of other ship's true motion.
DRM	Direction of relative movement; always in the direction of $R_{00} \rightarrow M_{03} \rightarrow M_{06} \dots$	STM	Speed of other ships true motion.
SRM	Speed of relative movement.	$R_{00}-M_{03}$	The relative (DRM-SRM) vector; always in the direction of $R_{00} \rightarrow M_{03} \rightarrow M_{06} \dots$
CPA	Closest point of approach.	R_c	The head of own ship's true (course-speed) vector following course or speed change or both to obtain a new RML.
MCPA	Minutes to CPA.	R_c-M_{03}	The relative (DRM-SRM) vector; always in the direction of the new RML ($M_x M_{x+3} M_{x+6} \dots$).
TCPA	Time to CPA.	$T_{03}-R_c$	Own ship's true (course-speed) vector required to obtain new RML.

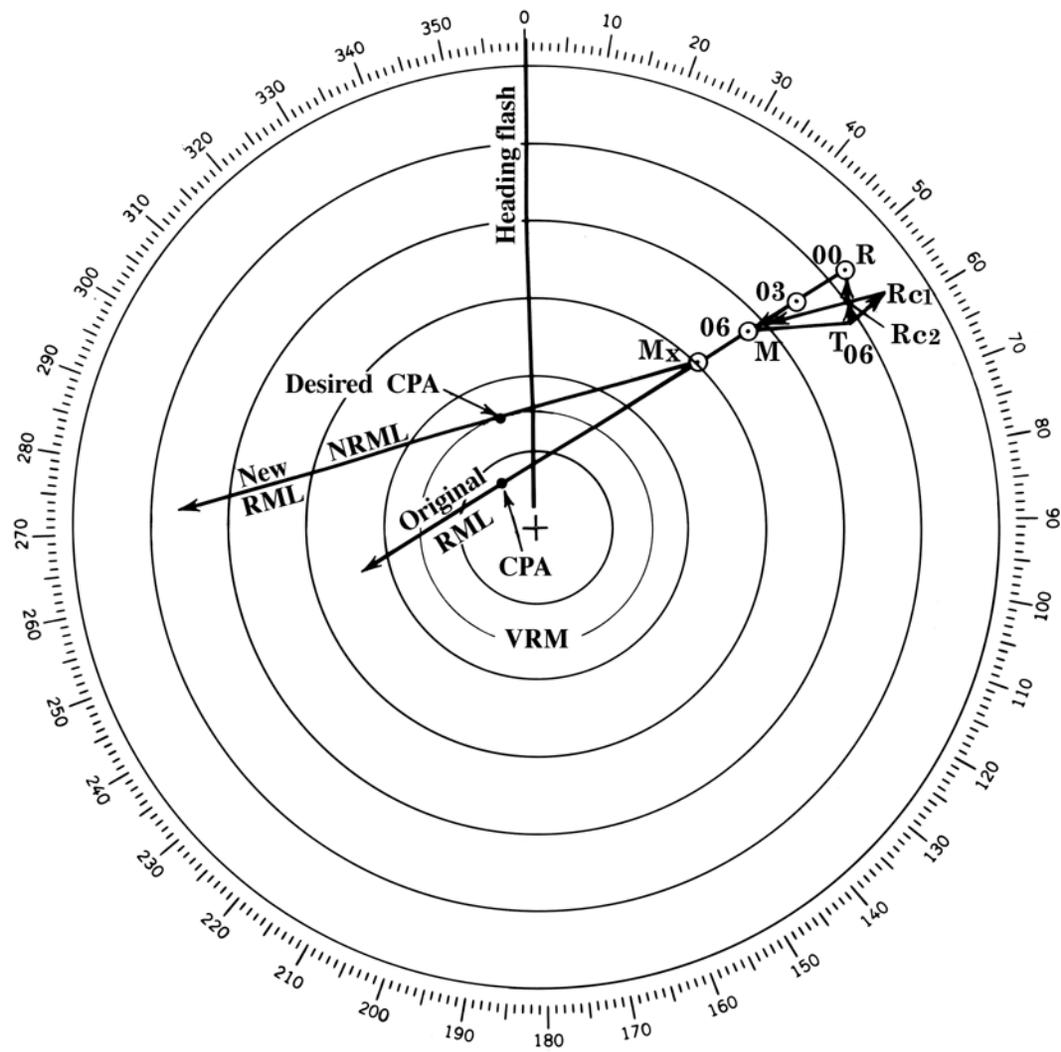


Figure 3.40 - Alternative plotting symbols.

ALTERNATIVE GRAPHICAL SOLUTIONS ON THE REFLECTION PLOTTER

R-T-M TRIANGLE

CLOSEST POINT OF APPROACH

To determine the closest point of approach (CPA) of a contact by graphical solution on the reflection plotter, follow the procedure given below.

- (1) Plot at least three relative positions of the contact. If the relative positions lie in a straight or nearly straight line, fair a line through the relative positions. Extend this relative movement line (RML) past the center of the PPI.
- (2) Crank out the variable range marker (VRM) until the ring described by it is tangent to the RML as shown in figure 3.41. The point of tangency is the CPA.
- (3) The range at CPA is the reading of the VRM counter; the bearing at CPA is determined by means of the mechanical bearing cursor, parallel-line cursor, or other means for bearing measurement from the center of the PPI.

Note: The RML should be reconstructed if the contact does not continue to plot on the RML as originally constructed.

TRUE COURSE AND SPEED OF CONTACT

To determine the true course and speed of a contact by graphical solution on the reflection plotter, follow the procedure given below.

- (1) As soon as possible after a contact appears on the PPI, plot its relative position on the reflection plotter. Label the position with the time of the observation as shown in figure 3.41. As recommended in Alternative Plotting Symbols, the first plot is labeled as time zero. Subsequent relative positions are plotted and labeled at 3-minute intervals, preferably using a suitable timing device which can be reset to zero time when desired.
- (2) Examine the relative plot to determine whether the contact is on a steady course at constant speed. If so, the relative positions plot in a straight or nearly straight line; the relative positions are equally spaced for equal time intervals as shown in figure 3.41.
- (3) With the contact on a steady course at constant speed, R_{00} , the plot for zero time, is the origin of the relative (DRM-SRM) vector. At plot time 03, this vector is $R_{00}-M_{03}$; at plot time 06, this vector is $R_{00}-M_{06}$. Note that the relative motion and relative vector are always in the direction of $R_{00}M_{03}M_{06}$.

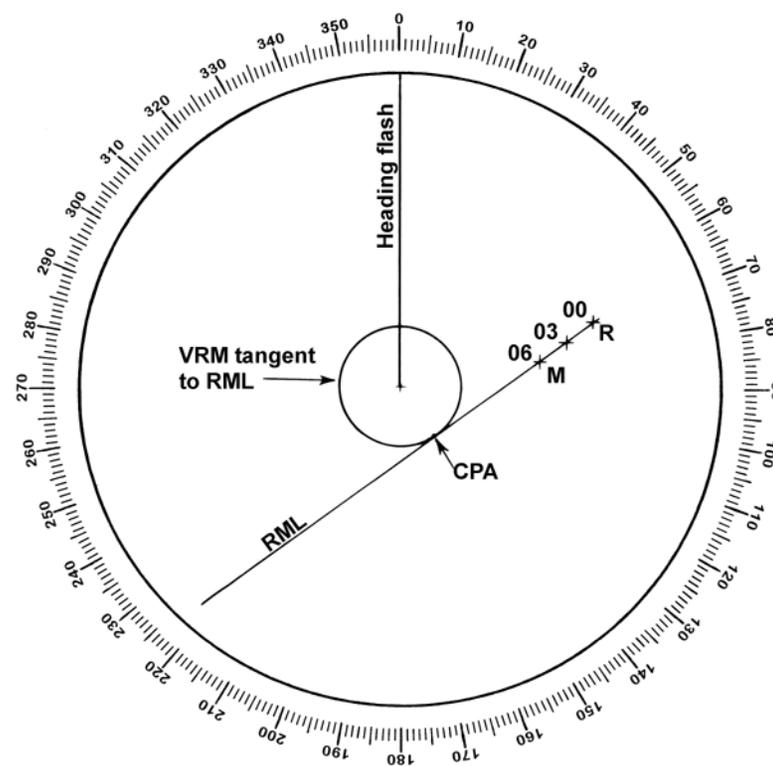


Figure 3.41 - Closest point of approach.

- (4) Crank the parallel-line cursor until its lines are parallel to the heading flash. As shown in figure 3.42, place the standard plotting period scale so that its straightedge is parallel to the lines of the cursor and the heading flash and the zero speed graduation is at R_{00} .
- (5) Given that own ship is on course 000° at 30 knots and the range scale setting is 12 miles, the standard plotting period is 6 minutes; the 30-knot graduation on the scale corresponds to T_{06} . The head of the other ship's true (course-speed) vector is at M_{06} beyond R_{00} in the direction of relative movement (DRM).

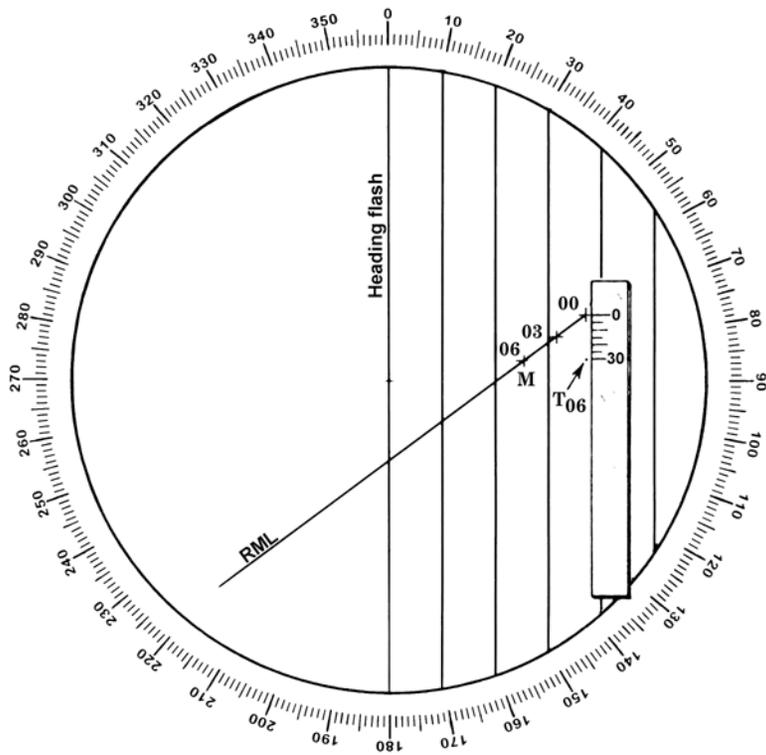


Figure 3.42 - Use of the standard plotting period scale.

- (6) Construct the other ship's true (course-speed) vector $T_{06}-M_{06}$.
- (7) Crank the parallel-line cursor so that its lines are parallel to vector $T_{06}-M_{06}$ as shown in figure 3.43. The other ship's direction of true motion (DTM) is read on the true bearing dial using the radial line of the parallel-line cursor; the other ship's speed of true motion (STM) is measured by the standard plotting period scale or estimated by visual comparison with own ship's true vector $T_{06}-R_{00}$. For example, if $T_{00}-M_{06}$ is about two-thirds the length of $T_{06}-R_{00}$, the other ship's speed of true motion is about two-thirds own ship's speed.

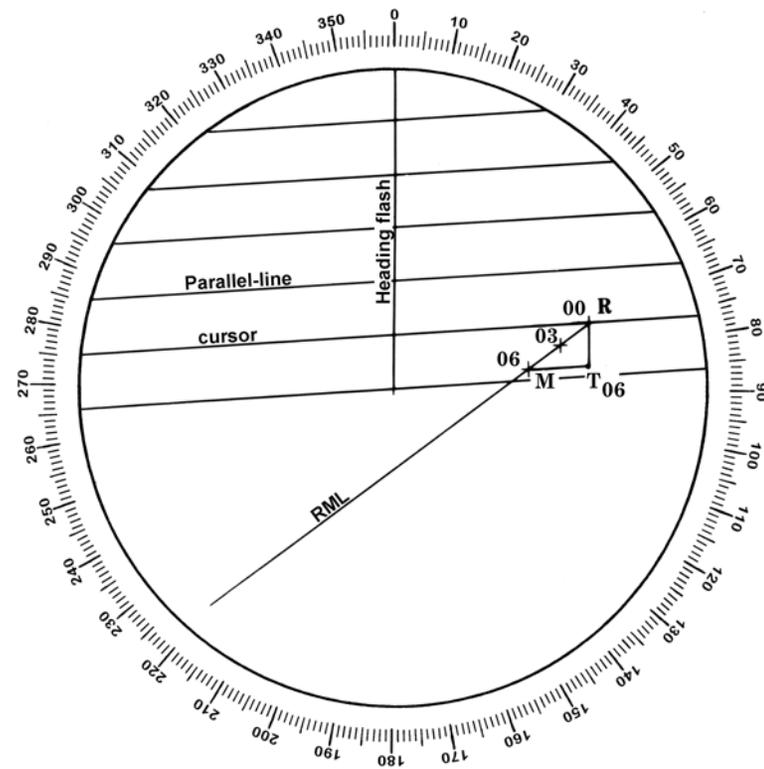


Figure 3.43 - Use of parallel-line cursor to find true course of contact.

COURSE TO PASS AT SPECIFIED CPA

The procedure for determining own ship's new course and/or speed to reduce the risk of collision is given below.

(1) Continuing with the plot used in finding the true course and speed of the other ship, mark the point of execution (M_x) on the RML as shown in figure 3.44. M_x is the position of the contact on the RML at the planned time of evasive action. This action may be taken at a specific clock time or when the range to the other ship has decreased to a specified value.

(2) Crank the VRM to the desired distance at CPA. This is normally the distance specified for the **danger** or **buffer zone**. If the fixed range rings are displayed and one range ring is equal to this distance, it will not be necessary to use the VRM.

(3) From M_x , draw the new RML tangent to the VRM circle. Two lines can be drawn tangent to the circle, but the line drawn in figure 3.44 fulfills the requirement that the other ship pass ahead of own ship. If the new RML crosses the heading flash, the other ship will pass ahead.

(4) Using the parallel-line cursor, draw a line parallel to the new RML through M_{06} or the final plot (relative position) used in determining the course and speed of the contact. This line is drawn from M_{06} in a direction opposite to the new DRM because the new relative speed (DRM-SRM) vector will be parallel to the new RML and the head (M_{06}) of the new vector ($R_c M_{06}$) will lie in the new DRM away from the origin, R_c .

(5) Avoiding by course change only, the magnitude of own ship's true (course-speed) vector remains constant. Therefore, the same speed graduation on the standard plotting interval scale used to construct $T_{06}-R_{00}$ is set at T_{06} . The scale is then adjusted so that its zero graduation intersects the line drawn parallel to the new RML. As shown in figure 3.44, the intersection at R_c is the head of the required new true (course-speed) vector for own ship, $T_{06}-R_c$.

The previously described use of the plastic ruler, in effect, rotates vector $T_{06}-R_c$ about its origin; the head of the vector describes an arc which intersects the line drawn parallel to the new RML at R_c .

If the speed of the contact were greater than own ship's speed, there would be two intersections and, thus, two courses available to produce the desired distance at CPA. Generally, the preferred course is that which results in the higher relative speed (the longer relative speed vector) in order to expedite safe passing.

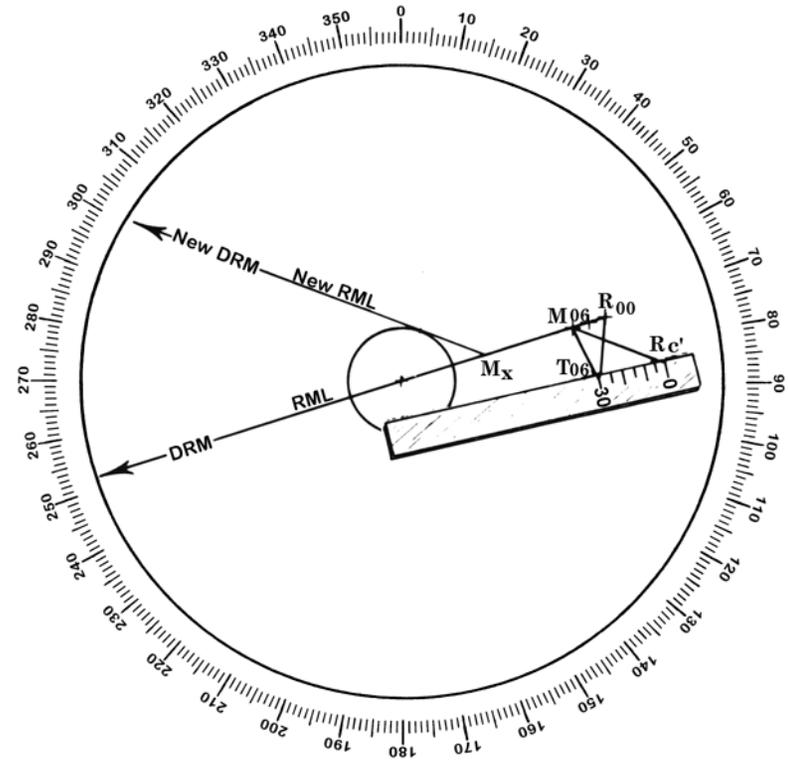


Figure 3.44 - Evasive action.

SPECIAL CASES

In situations where contacts are on courses opposite to own ship's course or are on the same course as own ship but at slower or higher speeds, the relative movement lines are parallel to own ship's course line. If a contact has the same course and speed as own ship, there is no relative movement line; all relative positions lie at one point at a constant true bearing and distance from own ship. If a contact is stationary or dead in the water, the relative vector $R-M$ and own ship's true vector $T-R$ are equal and opposite, and coincident. With T and M coincident, there is no vector $T-M$.

The solutions of these special cases can be effected in the same manner as those cases resulting in the conventional vector triangle. However, no vector triangle is formed; the vectors lie in a straight line and are coincident.

In figure 3.45 contacts A, B, C, and D are plotted for a 12-minute interval; own ship's true vector $T_{12-R_{00}}$ is scaled in accordance with this time. Inspection of the plot for contact A reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact B reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed minus the contact's speed. The contact is on the same course as own ship at about one-

half own ship's speed.

Inspection of the plot for contact C reveals that the DRM is opposite to own ship's course; the relative speed is equal to own ship's speed plus the contact's speed. The contact is on a course opposite to own ship's course at about the same speed.

Inspection of the plot for contact D reveals that the DRM is the same as own ship's course; the relative speed is equal to the contact's speed minus own ship's speed. The contact is on the same course as own ship at about twice own ship's speed.

BLACK LIGHT ILLUMINATION

"Black light" illumination of the reflection plotter permits the use of the standard plotting period scale without the use of notches in the scale that would otherwise be required. However, when this type of illumination is used to facilitate scaling by means of a graduated scale, such illumination should be used only while scaling because it tends to make the video on the PPI less visible. Therefore, means should be readily available to extinguish this illumination when it is not required.

The shaft of the grease pencil as well as the standard plotting period scale should be fluorescent.

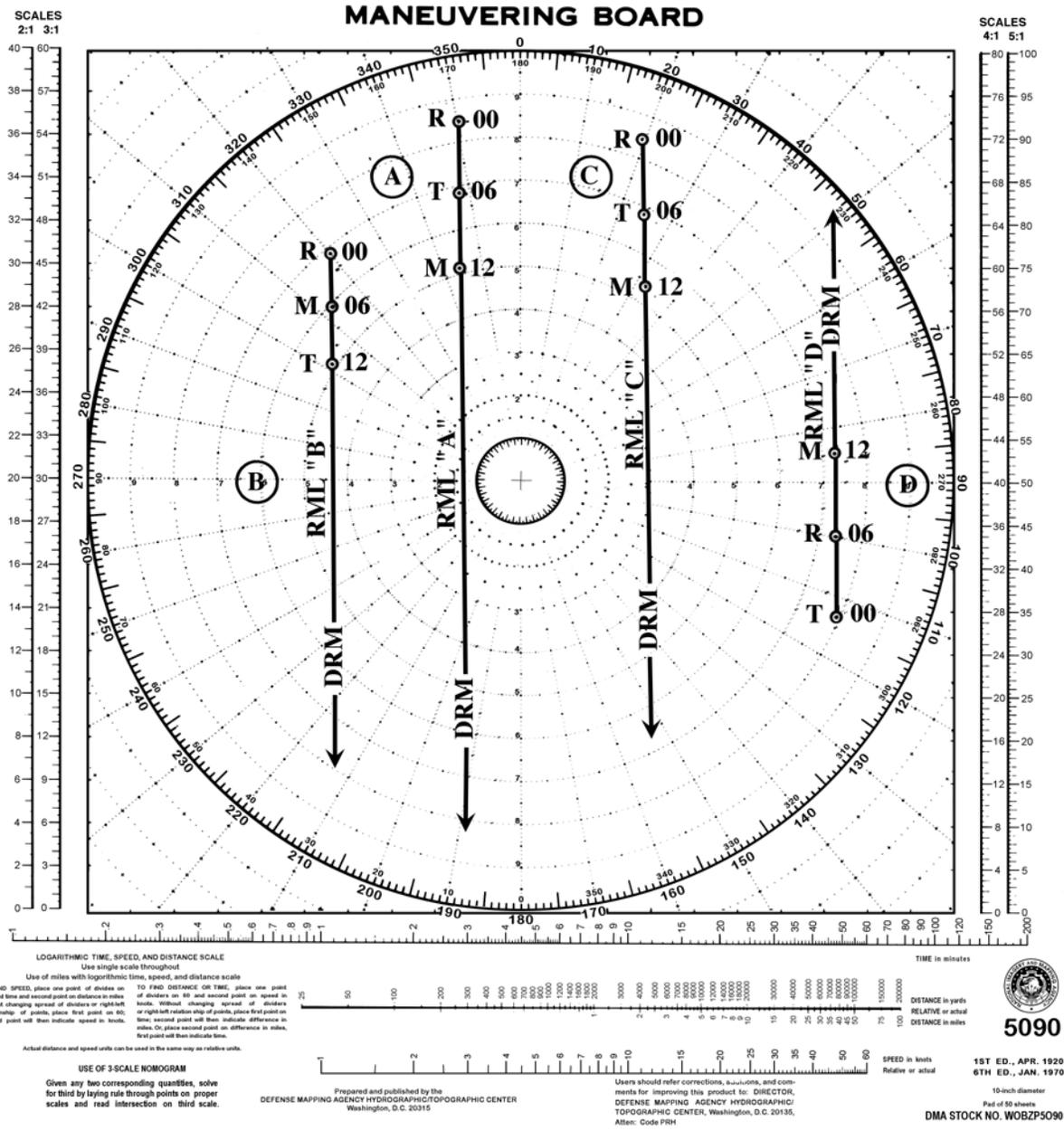


Figure 3.45 - Special cases.

EXAMPLES

R-T-M TRIANGLE

- EXAMPLE 9 . DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)
- EXAMPLE 10 . COURSE AND SPEED OF A RADAR CONTACT
- EXAMPLE 11 . COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD
- EXAMPLE 12 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own ship's Speed is Greater Than That of Other Ship
- EXAMPLE 13 . COURSE TO PASS A SHIP AT A SPECIFIED CPA
Own ship's Speed is Less Than That of Other Ship
- EXAMPLE 14 . VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER
- EXAMPLE 15 . AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING TRUE COURSES AND SPEEDS OF THE CONTACTS

EXAMPLE 9

DETERMINATION OF CLOSEST POINT OF APPROACH (CPA)

Situation:

With own ship on course 070° and the radar set on the 12-mile range scale, the other ship is observed as follows:

Time	Bearing	Range (miles)	Rel. position
1000	050°	9.0	R00
1006	049°	7.5	M06
1012	047°	6.0	M12

Required:

- (1) Direction of relative movement. (DRM)
- (2) Speed of relative movement. (SRM)
- (3) Bearing and range at closest point of approach. (CPA)
- (4) Estimated time of arrival at CPA.

Solution:

(1) Plot and label the relative positions, R_{00} , M_{06} , and M_{12} , using the 1:1 scale; fair a line through the relative positions; extend this line, the *relative movement line (RML)*, beyond the center of the Maneuvering Board.

(2) The direction of the RML from the initial plot R_{00} is the direction of relative movement (DRM): 236° .

(3) Measure the relative distance between any two timed plots on the RML, preferably between the two best plots with the greatest time separation. In this instance, measure the distance between R_{00} and M_{12} : 3.0 miles. Using the corresponding time interval ($1000 - 1012 = 12^m$), obtain the speed of relative movement (SRM) from the Logarithmic Time-Speed-Distance Scale at the bottom of the Maneuvering Board: 15 knots.

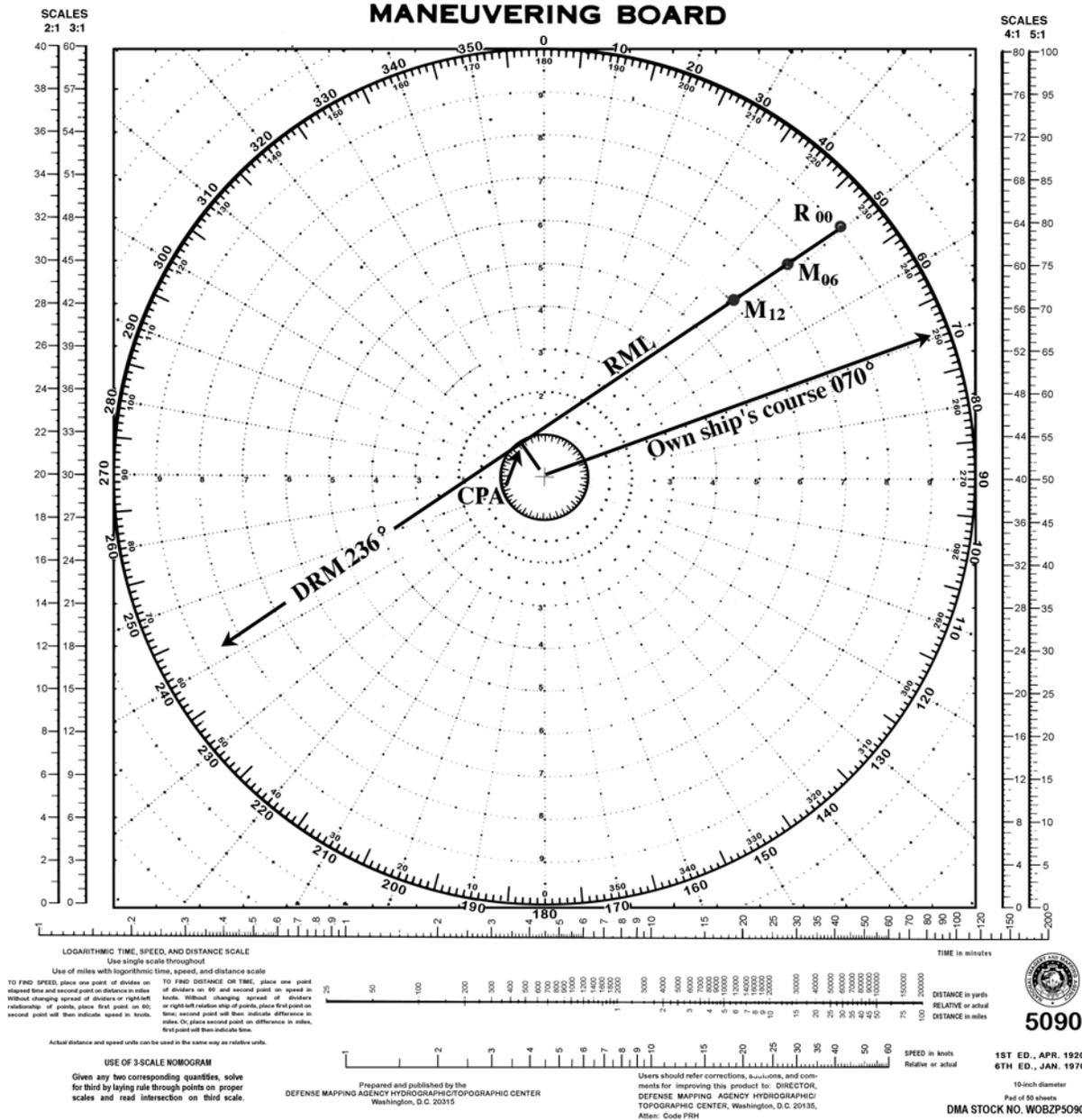
(4) From the center of the Maneuvering Board, draw a line perpendicular to the RML; label the intersection CPA. The direction of the CPA from the center of the plotting sheet, i.e., own ship's position, is the bearing of the CPA: 326° ; the distance from the center or own ship is the range at CPA: 0.9 mile.

(5) Measure the distance from M_{12} to CPA: 6.0 miles. Using this distance and the speed of relative movement (SRM): 15 knots, obtain the minutes to CPA (MCPA) from 1012 (the time of plot M_{12}) by means of the Time-Speed-Distance Scale: 24m. The estimated time of arrival at CPA is $1012 + 24^m = 1036$.

Answers:

(1) DRM 236° (2) SRM 15 knots; (3) CPA 326° , 0.9 mile; (4) ETA at CPA 1036.

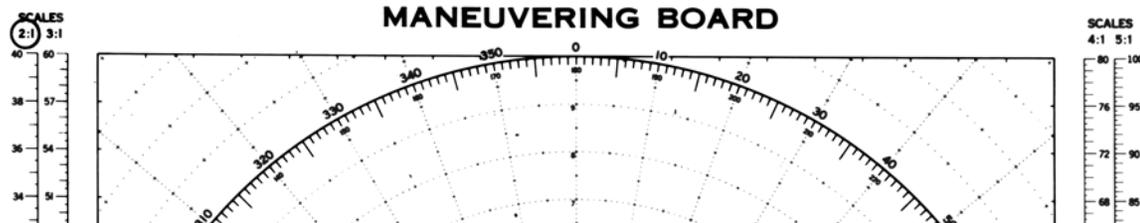
EXAMPLE 9



Notes:

1. There should be sufficient plots to insure accurate construction of the RML faired through the plots. Should only two plots be made, there would be no means of detecting course or speed changes by the other ship. The solution is valid only if the other ship maintains course and speed constant. Preferably, the timed plots should be made at equal time intervals. Equal spacing of the plots timed at regular intervals and the successive plotting of the relative positions in a straight line indicate that the other ship is maintaining constant course and speed.

2. This transfer plotting solution required individual measurements and recording of the ranges and bearings of the relative position of ship M at intervals of time. It also entailed the normal requirement of plotting the relative positions on the PPI or reflection plotter. Visualizing the concentric circles of the Maneuvering Board as the fixed range rings of the PPI, a faster solution may be obtained by fairing a line through the grease pencil plot on the PPI and adjusting the VRM so that the circle described is tangent to or just touches the RML. The range at CPA is the setting of the VRM; the bearing at CPA and the DRM may be found by use of the parallel-line cursor (parallel index). The time of the CPA can be determined with reasonable accuracy through visual inspection, i.e., the length along the RML from M_{12} to CPA by quick visual inspection is about twice the length between R_{00} and M_{12} , representing about 24 minutes.



EXAMPLE 10

COURSE AND SPEED OF A RADAR CONTACT

Situation:

Own ship is on course 340° , speed 15 knots. The radar is set on the 12-mile range scale. A radar contact is observed to be changing course, and possibly speed, between times 0953 and 1000. While keeping a close watch of the relative movement, the relative positions of the contact are marked at frequent intervals on the reflection plotter by grease pencil.

Required:

(1) Course and speed of the contact when it has steadied on course and speed.

Solution:

(1) The solution is started before the contact steadies on course and speed through planning:

(a) Since the contact is being observed on the 12-mile range scale, the standard plotting period for use with the six fixed range rings is 6 minutes.

(b) The observer anticipates that after the contact has been observed to be on a steady course at constant speed for 6 minutes he will be able to obtain a rapid solution by using the spacing between range rings as a speed scale.

(2) Observation of the PPI reveals that between 1000 and 1006, the contact is on a steady course at constant speed (successive plots form a straight line on the scope; plots for equal time intervals are equally spaced). Draw the relative movement line (RML) from the 1000 plot (R_{00}) through the 1006 plot (M_{06}), extending beyond the center of the PPI.

(3) Set center line of parallel-line cursor to heading flash. Place the standard plotting period scale parallel to the lines on the cursor and with its zero graduation at R_{00} . The 15-knot graduation on the scale corresponds to T_{06} . Two sides of the vector diagram (triangle) have been formed: $T_{06}-R_{00}$ and $R_{00}-M_{06}$. The solution is obtained by completing the triangle to form the contact's true (course-speed) vector $T_{06}-M_{06}$.

(4) The direction of the contact's true motion (DMT) can be read by adjusting the parallel-line cursor parallel to $T_{06}-M_{06}$. After such adjustment, the radial line of the cursor indicates the DTM or true course of the contact. The speed of the contact's true motion (STM) can be measured by the standard plotting period scale, or it can be estimated by comparing the length of $T_{06}-M_{06}$ with $T_{06}-R_{00}$, the speed of which in knots is known.

Answers:

(1) Course 252° , speed 25 knots.

EXAMPLE 10

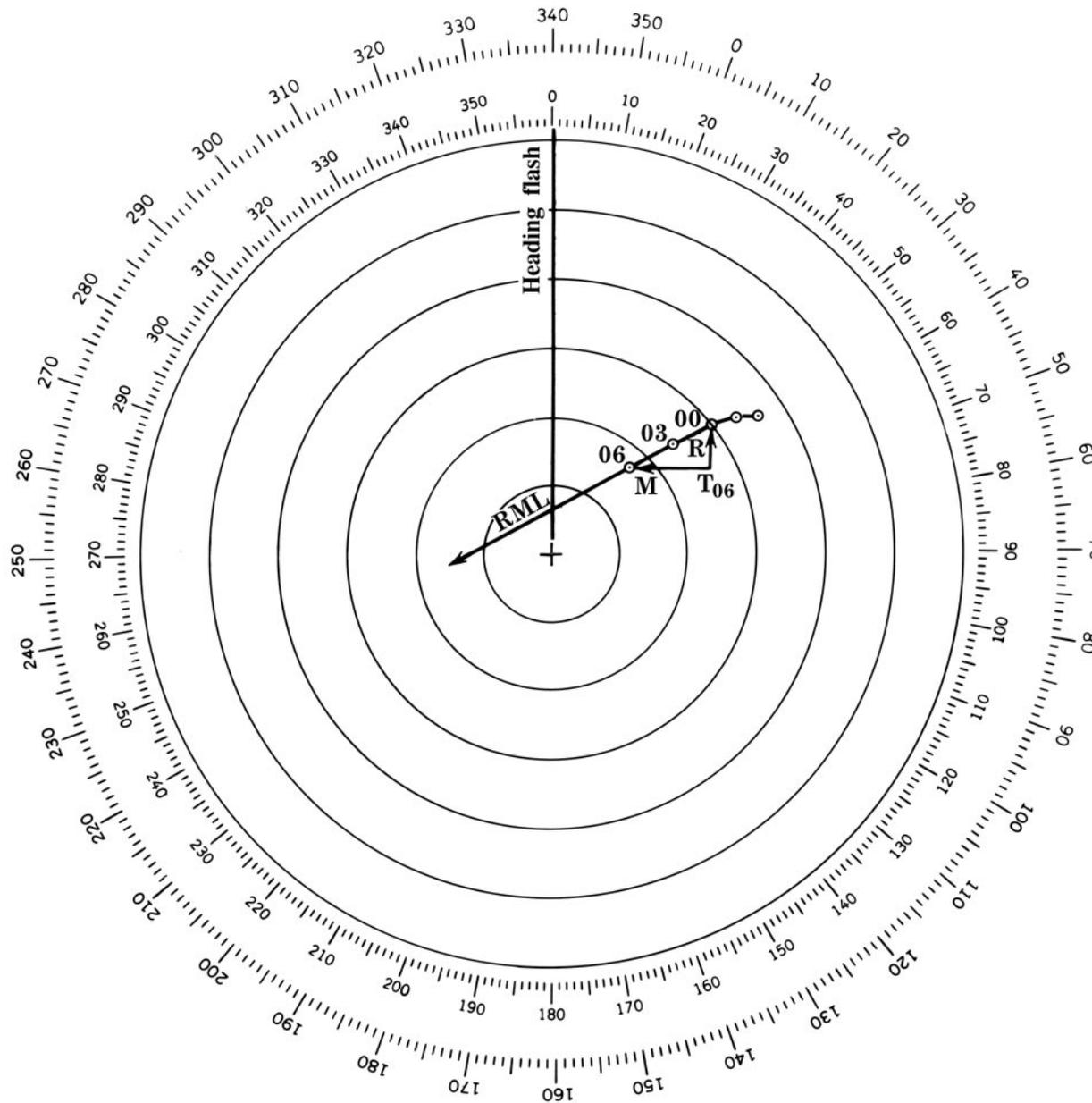
Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Notes:

1. In this example with the contact observed to be changing course, and possibly speed, between times 0953 and 1000, it was necessary to delay construction of own ship's true vector ($T_{06}-R_{00}$) until after 1000. However, when it is not known that the contact is on other than a steady course at constant speed, the solution can often be expedited by constructing $T_{06}-R_{00}$ soon after the initial observation and then determining whether the contact is on a steady course at constant speed. If such is the case, the triangle is completed at time 06.

2. With the display of the fixed range rings, a practical solution can be obtained without the use of the standard plotting period scale by visualizing the vector diagram (triangle) using the spacing between range rings as the speed scale.



EXAMPLE 11

COURSE AND SPEED OF RADAR CONTACT BY THE LADDER METHOD

Situation:

Own ship is on course 120° , speed 20 knots. The radar is set on the 6-mile range scale because small wooden vessels are expected to be encountered. The range scale setting is being shifted periodically to longer ranges for possible detection of distant targets. A radar contact is being plotted on the reflection plotter. Inspection of the plot reveals that the contact is on steady course at constant speed (see solution step (2) of example 10).

Required:

- (1) Course and speed of the radar contact.

Solution:

(1) With the decision made that the solutions will be obtained by rapid radar plotting, the radar observer further elects to use the Ladder Method in order to be able to *refine* the solution as the relative plot for the contact develops with time.

(2) Since the contact is being observed on the 6-mile range scale, the standard plotting period for use with the six fixed range rings is 3 minutes.

(3) Set the center line of the parallel-line cursor to heading flash. Place the standard plotting period scale parallel to the lines of the cursor and with its zero graduation at R_{00} . The 20-knot graduation on the scale corresponds to

T_{03} . The ladder is drawn in multiples and sub-multiples to $T_{03}-R_{00}$: The 40-knot graduation corresponds to T_{06} ; the 30-knot graduation corresponds to $T_{4.5}$; and the 10-knot graduation corresponds to $T_{1.5}$.

(4) With the assumption that the contact is on a steady course at constant speed, the first solution is obtained at time 1.5 (90 seconds) by constructing vector $T_{1.5}-M_{1.5}$. At time 03 it is seen that the contact is on a steady course at constant speed. The solution obtained at time 03 by completing vector $T_{03}-M_{03}$ is a refinement of the earlier solution. Assuming that the contact maintains course and speed, solutions obtained at later times should be of increasing accuracy.

(5) The direction of the contact's true motion (DTM) at time 06 can be read by adjusting the parallel-line cursor parallel to $T_{06}-M_{06}$. After such adjustment, the radial line of the cursor indicates the DTM or true course of the contact. The speed of the contact's true motion (STM) can be measured by the standard plotting period scale, or it can be estimated by comparing the length of $T_{06}-M_{06}$ with $T_{06}-R_{00}$, the speed of which in knots (20) is known. Note that although the 40-knot graduation on the standard plotting period scale corresponds to time 06, vectors $T_{1.5}-R_{00}$, $T_{03}-R_{00}$, $T_{4.5}-R_{00}$, and $T_{06}-R_{00}$ are all 20-knot vectors.

Answers:

- (1) Course 072° , Speed 22 knots.

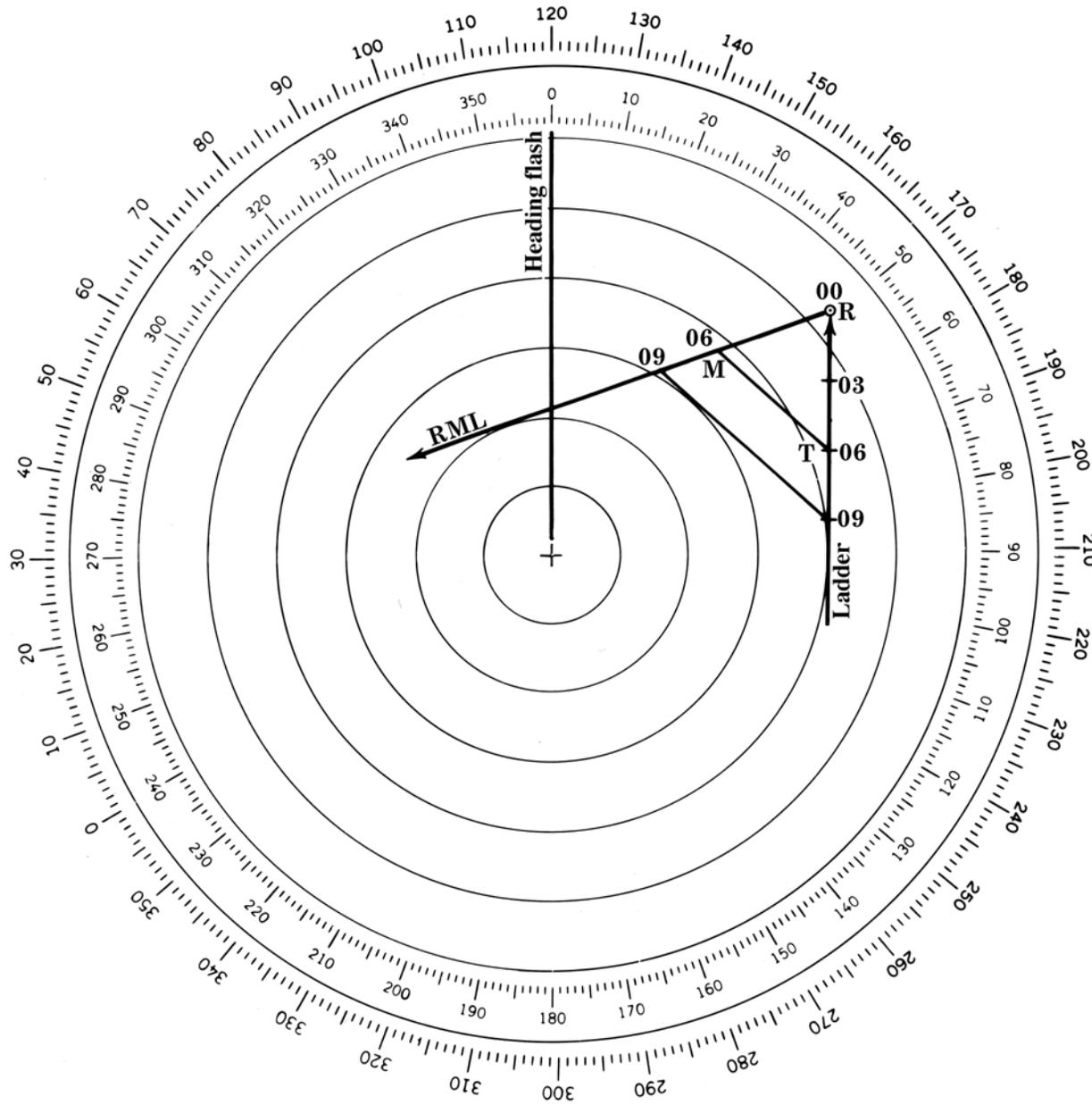
EXAMPLE 11

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 6-mile range setting

Notes:

1. Using the ladder method, the radar observer is able to obtain an approximate solution quickly and then refine the solution as the plot develops.
2. This solution was simplified by starting the timed plot at some tenth of an hour after the hour.



EXAMPLE 12

COURSE TO PASS A SHIP AT A SPECIFIED CPA (Own ship's speed is greater than that of other ship)

Situation:

Own ship is on course 188° , speed 18 knots. The radar is set on the 12-mile range scale. Between times 1730 and 1736 a ship has been observed to be on a collision course with own ship. By rapid radar plotting, it is found to be on course 258° at 12 knots. The visibility is 2.0 nautical miles.

Required:

(1) Course of own ship at 18 knots to pass ahead of the other ship with a CPA of 3.0 nautical miles if course is changed to the right when the range is 6.5 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course and speed of the other ship, plot M_x on the RML 6.5 nautical miles from own ship. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x draw a line tangent to the VRM circle. From M_x two lines can be drawn tangent to the circle, but the line as drawn fulfills the requirement that own ship pass ahead of the other ship or that the other ship pass astern of own ship.

(2) From the origin of the true vectors of the vector triangle used in finding the DTM and STM of the other ship, T_{06} , describe an arc of radius equal to the length of $T_{06}-R_{00}$.

(3) With the aid of the parallel-line cursor, draw a line through M_{06} parallel to the new RML to intersect the arc drawn in (2).

(4) The intersection of the arc with the line through M_{06} parallel to the new RML establishes the head of vector $T_{06}-R_c$, own ship's true (course-speed) vector required to obtain new RML.

Answers:

(1) Course 218° .

Notes:

1. Actually the arc intersecting the line drawn from M_{06} in a direction opposite to the new DRM would also intersect the same line if extended in the new DRM. But a new course of own ship based upon this intersection would reverse the new DRM or reverse the direction the other ship would plot on the new RML.

2. If the speed of the other ship were greater than that of own ship, there would be two courses available at 18 knots to produce the desired distance at CPA.

EXAMPLE 12

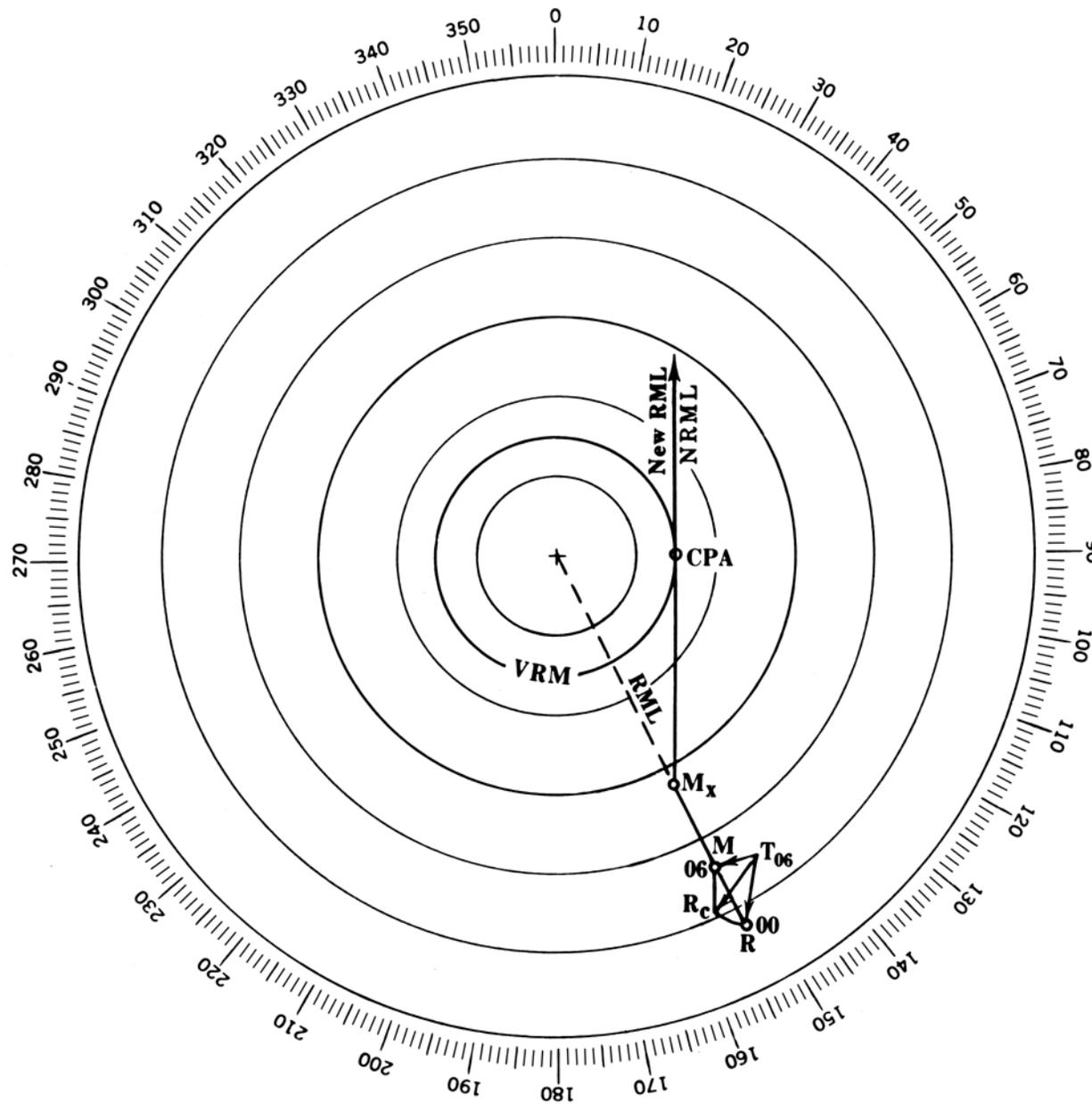
North-Upward Stabilized PPI Display

Scale: 12-mile range setting

Notes: (continued)

Generally, the preferred course is that which results in the highest relative speed in order to expedite the safe passing.

3. After own ship's course has been changed, the other ship should plot approximately along the new RML, as drawn and in the desired direction of relative movement. This continuity of the plot following a course change by own ship is one of the primary advantages of a stabilized display. Immediately following any evasive action, one should inspect the PPI to determine whether the target's bearing is changing sufficiently and in the desired direction. With the stabilized display, the answer is before the radar observer's eyes.



EXAMPLE 13

COURSE TO PASS SHIP AT A SPECIFIED CPA (Own ship's speed is less than that of other ship)

Situation:

Own ship is on course 340° , speed 15 knots. The radar is set on the 12-mile range scale. Between times 0300 and 0306, a ship has been observed to be on a collision course with own ship. By rapid radar plotting, it is found to be on course 249° at 25 knots. The visibility is 2.0 nautical miles.

Required:

(1) Course of own ship at 15 knots to pass astern of the other ship with CPA of 3.0 nautical miles if course is changed to the right when the range is 6.0 nautical miles.

Solution:

(1) Continuing with the plot on the PPI used in finding the true course, speed, and CPA of the other ship, plot M_x on the RML 6.0 nautical miles from own ship. Adjust the VRM to 3.0 nautical miles, the desired distance at CPA. From M_x two lines can be drawn tangent to the VRM circle, but the line as drawn fulfills the requirement that own ship pass astern of the other ship.

(2) From the origin of the true vectors of the vector triangle used in finding the DTM and STM of the other ship, T_{06} , describe an arc of radius equal to $T_{06}-R_{00}$.

(3) With the aid of the parallel-line cursor, draw a line through M_{06}

parallel to the new RML to intersect the arc drawn in (2).

(4) Since the speed of the other ship is greater than that of own ship, the arc intersects the line through M_{06} at two points. Each intersection establishes a head of a possible new own ship's true vector. Of the two possible vectors one provides a higher speed of relative movement than the other. Generally, true vector which provides the higher SRM or longer relative vector is chosen to expedite the passing. However, in this example a course change to the right is specified. This requires the use of vector $T_{06}-R_{c1}$, which provides the higher SRM.

(5) With this unstabilized, Heading-Upward PPI display, there is a complication arising from the plot shifting equal and opposite to the amount and direction of the course change. Some reflection plotter designs have provisions for either manual or automatic shifting of their plotting surfaces to compensate for the shifting of the plot. Without this capability, there is no continuity in the grease pencil plot following course changes of own ship. Consequently, it is necessary to erase the plot and replot the other ship's relative position when own ship steadies on course. With the VRM set to 3.0 miles, the new RML must be drawn tangent to the circle described by the VRM. The other ship must be watched closely to insure that its movement conforms with the new RML.

Answers:

(1) Course 030° .

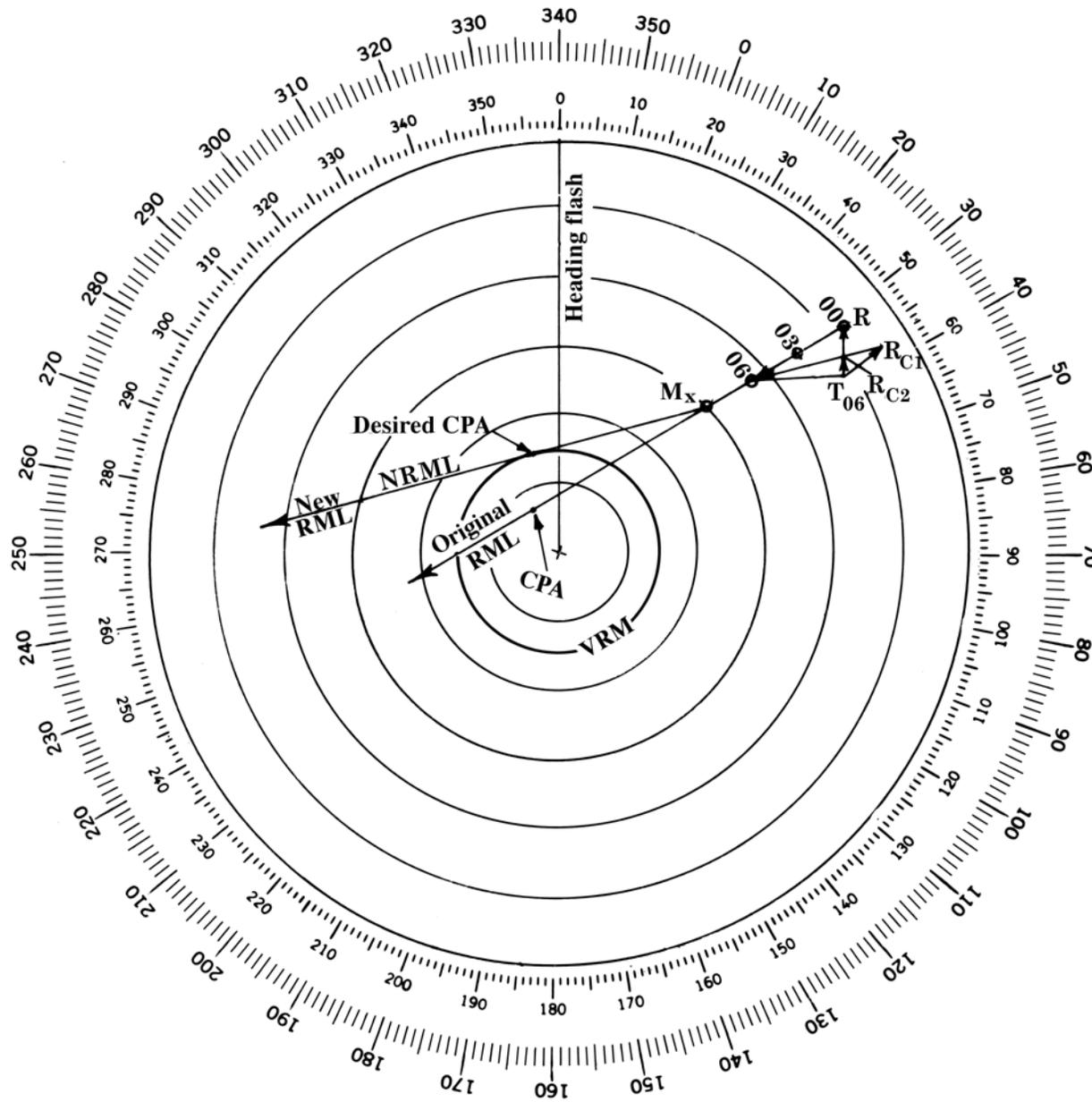
EXAMPLE 13

Heading-Upward Unstabilized PPI Display with Stabilized True Bearing Dial

Scale: 12-mile range setting

Note:

Examination of the plot reveals that if own ship maintains its original true course (340°), the intersection of the original true vector $T_{06}-R_{00}$ of own ship with the line drawn through M_{06} parallel to the new RML provides the head of the vector $T_{06}-R_{C2}$ required to effect the desired CPA without course change. Since the length of vector $T_{06}-R_{C2}$ is approximately half that of the original vector $T_{06}-R_{00}$, an instantaneous change to approximately half the original speed would produce the desired results. A lesser change of course to the right in conjunction with a speed reduction could be used to compensate for deceleration.



EXAMPLE 14

VERIFICATION OF FIXED OBJECTS OR RADAR CONTACTS DEAD IN THE WATER

Situation:

Own ship is on course 340° , speed 20 knots. The radar is set at the 24-mile range scale. Radar observations are made as follows:

<i>Time</i>	<i>Bearing</i>	<i>Range (miles)</i>	<i>Rel. position</i>
1200	017°	22.8	R00
1218	029°	17.4	M18
1236	046°	14.4	M36

The RML is parallel to and the DRM is opposite to own ship's course, 340° .

Required:

Course and speed of contact in order to verify whether it is dead in the water or a terrestrial object.

Solution:

(1) On the PPI, preferably one with a reflection plotter mounted thereon, plot R_{00} , M_{18} , M_{36} . Draw the relative movement line (RML) through these relative positions.

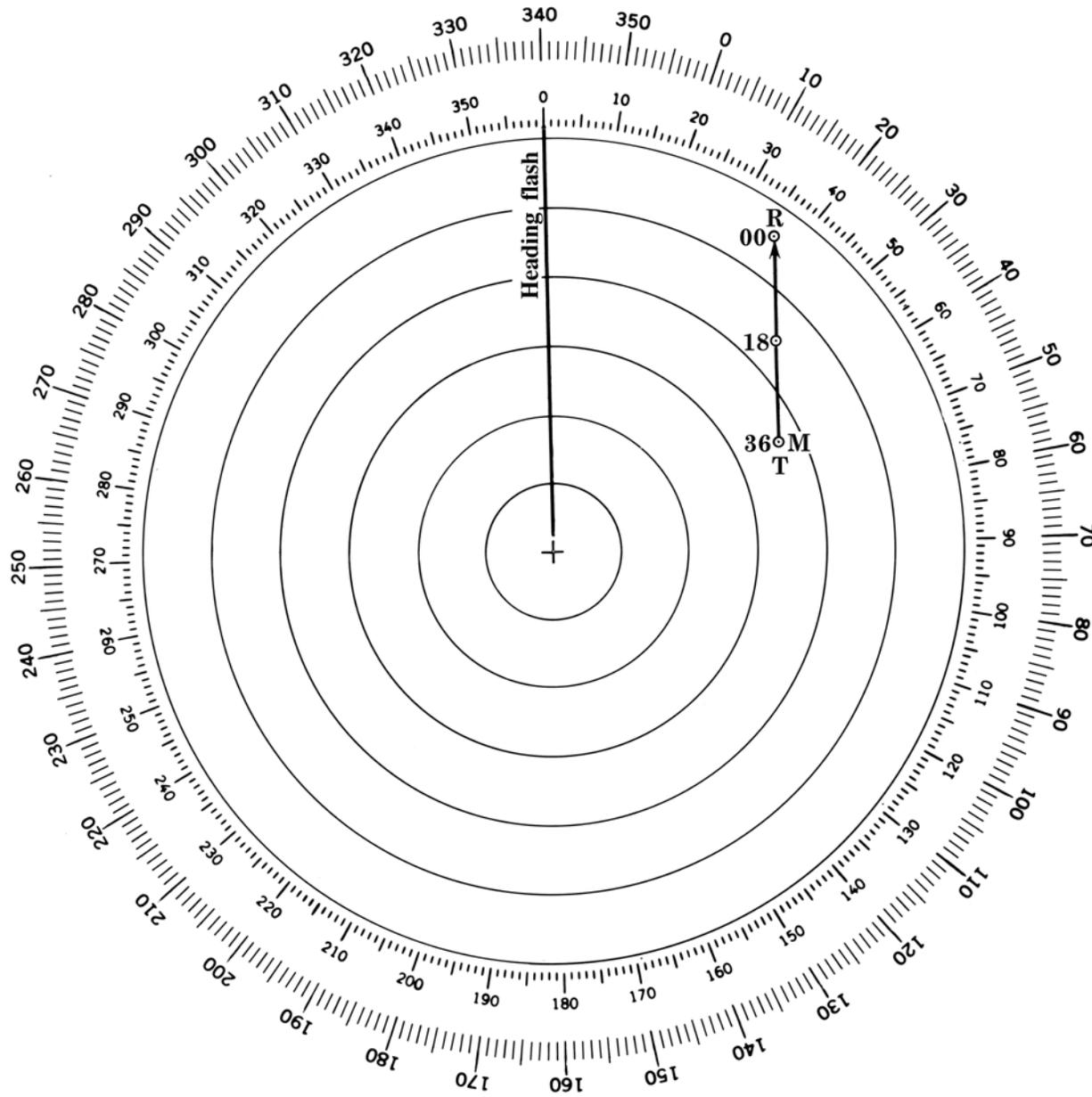
(2) Using the same distance scale as the radar range setting, determine the length of the true (course-speed) vector $T-R$ of own ship for a time interval of 36 minutes: 12 miles.

(3) Draw true vector $T_{36}-R_{00}$ in the direction of own ship's course with its head at relative position R_{00} . If after such graphical construction, the vector origin lies over relative position M_{36} , the length of the $T_{36}-M_{36}$ vector would be zero. Thus, the true speed of the observed contact would be zero. Even if the observed target is dead in the water or a fixed object, small observational and plotting errors will frequently indicate a small value of true speed for the contact.

EXAMPLE 14

**Heading-Upward
Unstabilized PPI Display
with Stabilized True
Bearing Dial**

Scale: 24-mile range setting



EXAMPLE 15

AVOIDANCE OF MULTIPLE CONTACTS WITHOUT FIRST DETERMINING THE TRUE COURSES AND SPEEDS OF THE CONTACTS

Situation:

Own ship is on course 000° , speed 20 knots. With the stabilized relative motion display radar set at the 12-mile range setting, radar contacts A, B, and C are observed and plotted directly on the PPI or reflection plotter. The plots at time 1000 are considered as the initial plots in the solution.

Required:

(1) Determine the new relative movement lines for contacts A, B, and C which would result from own ship changing course to 065° and speed to 15 knots at time 1006.

(2) Determine whether such course and speed change will result in desirable or acceptable CPA's for all contacts.

Solution:

(1) With the center of the PPI as their origin, draw own ship's true vectors $T-R$ and $T-R_c$ for the course and speed in effect or to be put in effect at times 1000 and 1006, respectively. Using the distance scale of the radar presentation, draw each vector of length equal to the distance own ship will travel through the water during the time interval of the relative plot (relative vector), 6 minutes. Vector $T-R$, having a speed of 20 knots, is drawn 2.0 miles in length in true direction 000° ; vector $T-R_c$, having a speed of 15 knots, is drawn 1.5 miles in length in true direction 065° .

(2) Draw a broken line between R and R_c .

(3) For contacts A, B, and C, offset the initial plots (A_1 , B_1 , and C_1) in the same direction and distance as the broken line $R-R_c$; label each such offset plot R_c .

(4) In each relative plot, draw a straight line from the offset initial plot R_c , through the final plot (A_2 or B_2 or C_2). The lines $R_c A_2$, $R_c B_2$, and $R_c C_2$ represent the new RML's which would result from a course change to 065° and speed change to 15 knots at time 1006.

Answers:

- (1) New RML of contact A—DRM 280°
New RML of contact B—DRM 051°
New RML of contact C—DRM 028°

(2) Inspection of the new relative movement lines for all contacts indicates that if all contacts maintain course and speed, all contacts will plot along their respective relative movement lines at safe distances from own ship on course 065° , speed 15 knots.

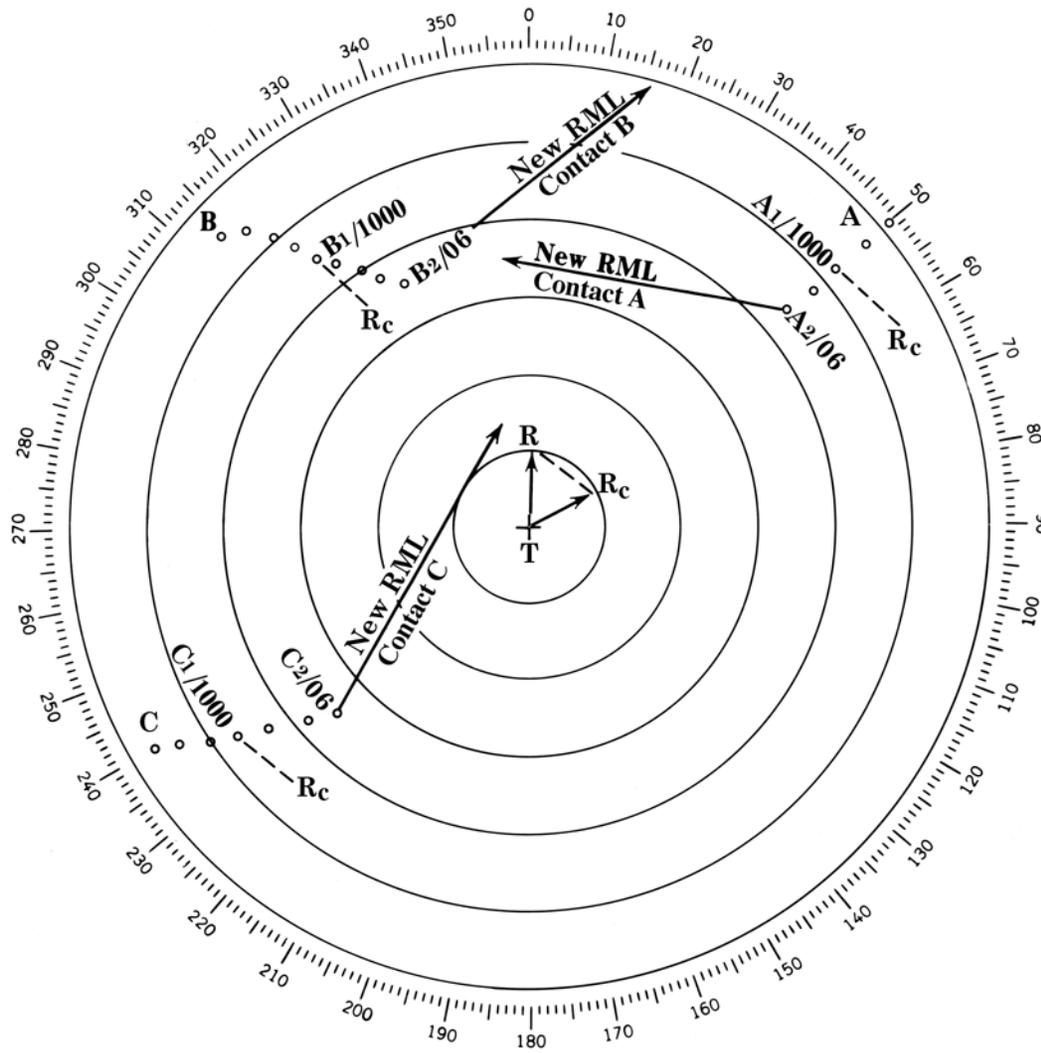
Explanation:

The solution is based upon the use of the relative plot as the relative vector. With each contact maintaining true course and speed, the true vector for each contact remains static while own ship's true vector is rotated about its origin T to the new course and changed in magnitude corresponding to the new speed.

EXAMPLE 15

**North-Upward
Stabilized PPI Display**

Scale: 12-mile range setting



PRACTICAL SOLUTION FOR CPA IN TRUE MOTION MODE

A practical solution for CPA in the true motion mode is dependent upon a feature normally provided with a true motion radar: some form of electronic bearing line (EBL) that can hold the range and bearing to which set. With the EBL originating at own ship moving in true motion on the PPI, it follows that if the EBL is held at an initial setting, the *end* of the EBL moves at the same speed as own ship along a parallel path. Or the *end* of the EBL follows own ship in true motion.

The true motions of own ship and of a contact are shown in figure 3.46 after observation for about 3 minutes. With own ship (at the center of the range rings) on course 000° at 20 knots, its tail has a length about equal to the 1-mile range ring interval, 1 mile being the distance own ship travels in 3 minutes at 20 knots. The tail of the contact bearing 045° at 4 miles indicates that the contact is on true course 280° at 30 knots. At this point it should be noted that the accuracy of the true motion displayed is dependent upon the accuracies of own ship course and speed inputs, particularly the speed input, and other errors associated with dead reckoning, such as those due to currents. Therefore, true motion solutions should be considered more approximate than those derived from stabilized relative motion displays.

Due to the fact that unlike relative motion, the true motion is not actually observed but is deduced from observed relative motion and *estimated* own ship course and speed over ground inputs, the true motion displayed on the PPI is better called *deduced* true motion.

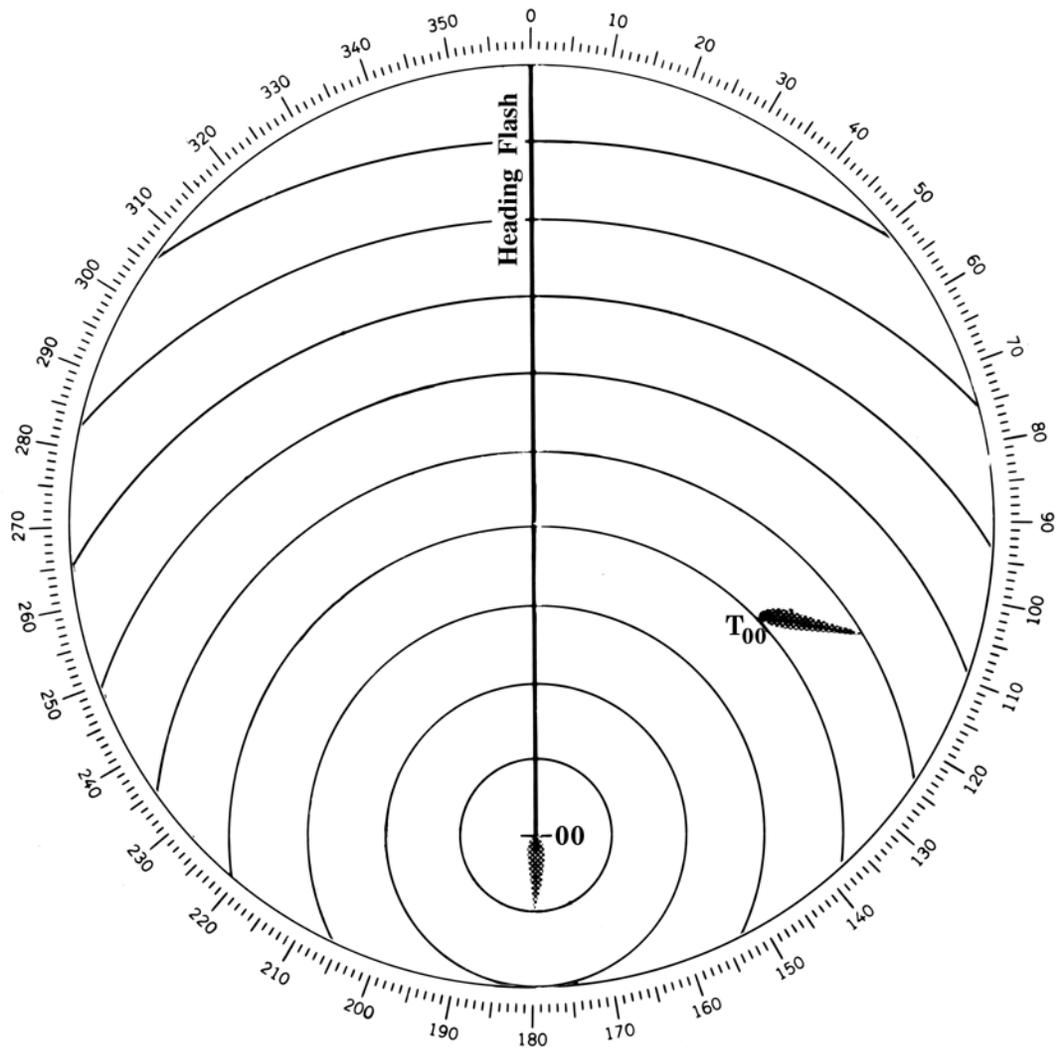
Figure 3.47 shows the EBL set at the contact at the initial position (time 00), which is labeled T_{00} . Own ship's position at this time is also labeled 00. If own ship is dead reckoned to the time 03 position as shown in figure 3.48, with the EBL holding the range and bearing to which set at time 00, the end of the EBL, moving in parallel motion at the same rate as the true motion of ship, arrives at R_{03} at the same time as own ship reaches the time 03 dead

reckoning position. During this time the contact moves in deduced true motion from its initial position, T_{00} to M_{03} as shown in figure 3.48. With the motions of own ship and of the contact producing the two true vectors of the *R-T-M* triangle, the triangle is completed to provide the relative vector R_{03} - M_{03} , the extension of which provides the RML, by means of which the CPA is determined. See figure 3.49.

With the EBL holding the initial range and bearing, it follows that the motions of the contact and of the end of the EBL from the initial position continuously generate the *R-T-M* triangle. Therefore the *R-T-M* triangle can be completed at any time between times 00 and 03 by constructing the relative vector from the end of the EBL to the position the contact occupies at the same time. Figure 3.50 shows the completion of the *R-T-M* triangle at times 01, 02, and 03. However, as indicated above, the triangle can be completed at any time. The relative vector and the RML can be obtained without any direct consideration of plot time. This fact enhances the practicality of the solution. It enables real-time visualization of the RML through observation of the current position of the contact in relation to the end of the moving EBL. This, in turn, enables the observer to determine the CPA very quickly.

Should the CPA be less than desired, a procedure similar to obtaining a desired CPA on a relative motion display (see examples 12 and 13) can be used. As shown in figure 3.51, the CPA is increased by course change only. The CPA is measured from the position own ship occupies on the PPI at plot time 03.

This practical solution for CPA in the true motion mode was devised by Captain Wayne M. Waldo, Head, All-weather Navigation Department, Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland.

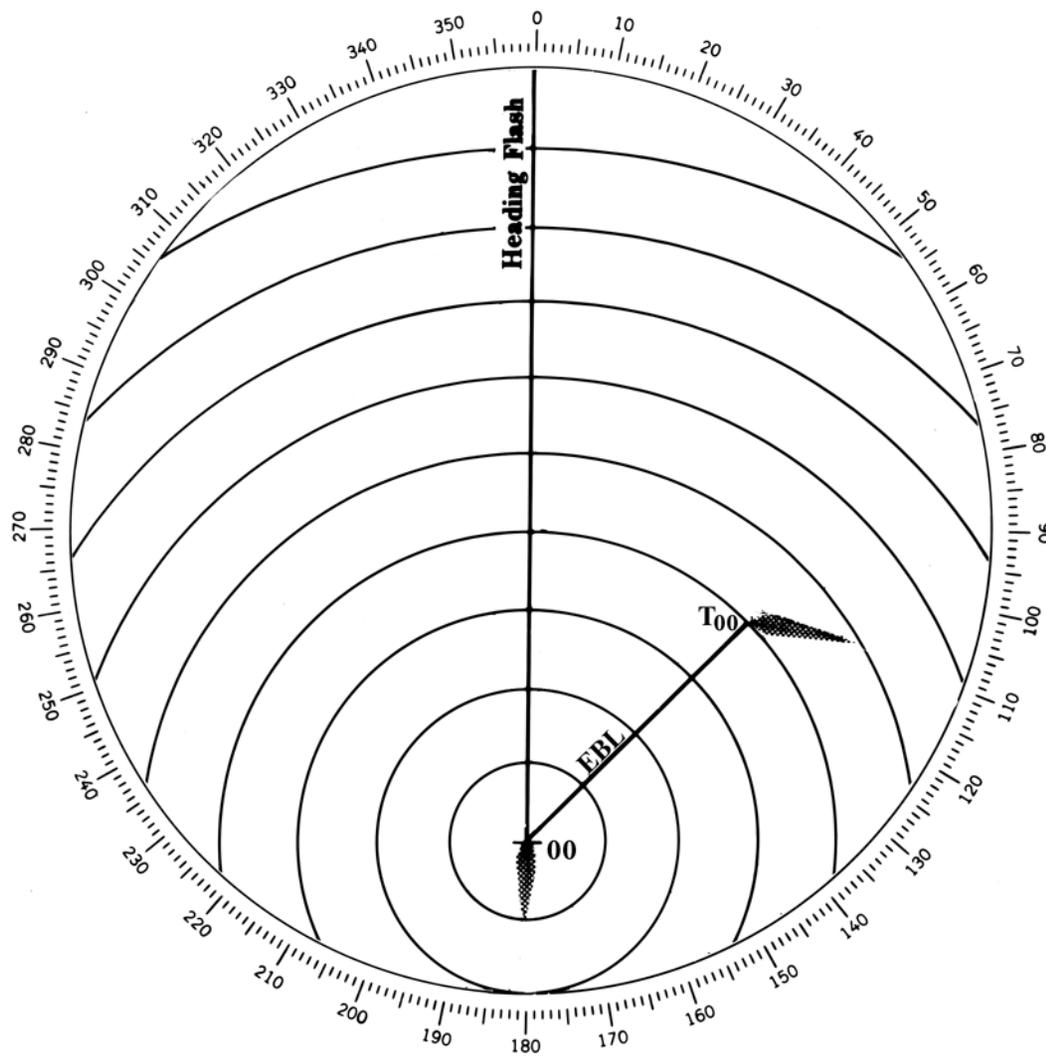


**Own ship's course 000°
speed 20 knots**

**Contact's course 280°
speed 30 knots**

Range-ring interval: 1 mile

Figure 3.46 - True motion display

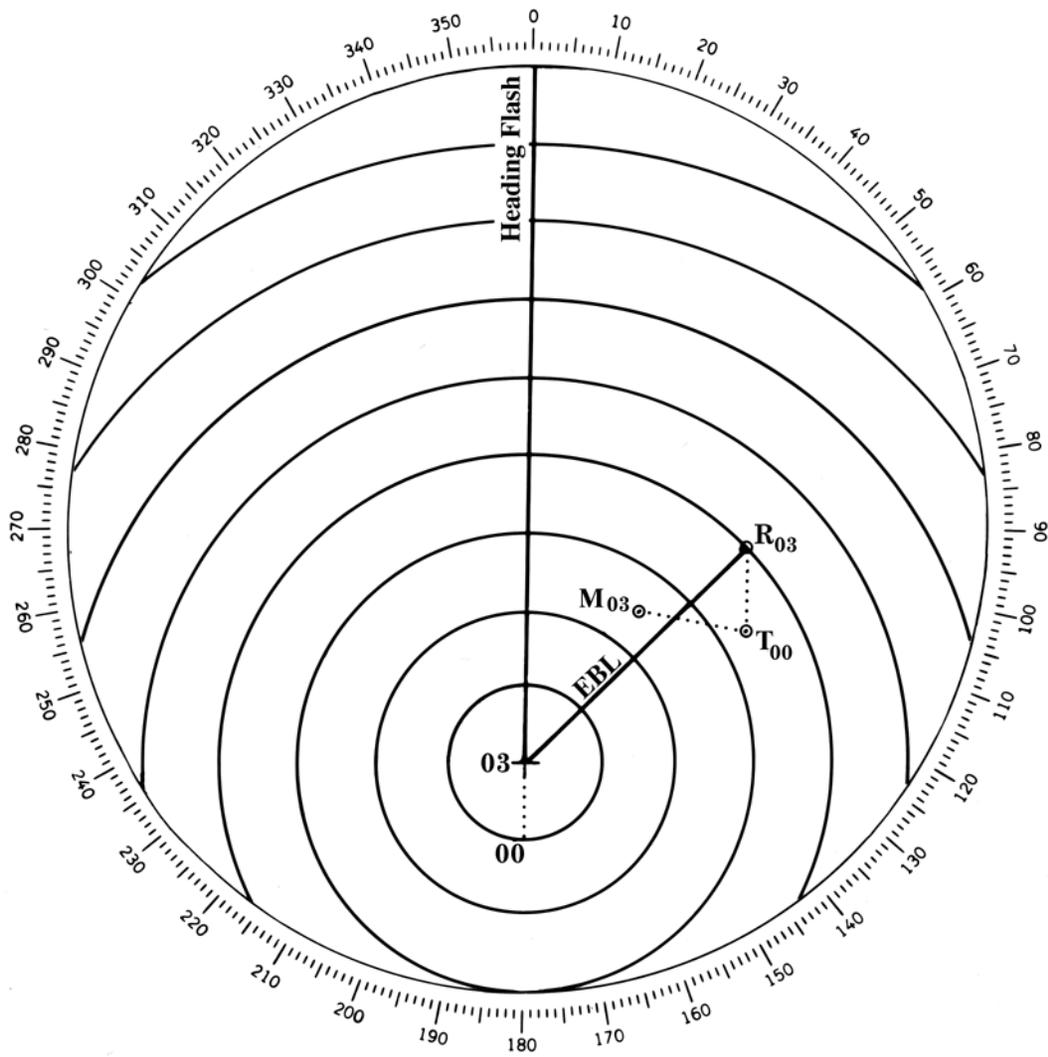


Own ship's course 000°
speed 20 knots

Contact's course 280°
speed 30 knots

Range-ring interval: 1 mile

Figure 3.47 - Electronic bearing line set at initial time position of contact moving in true motion.

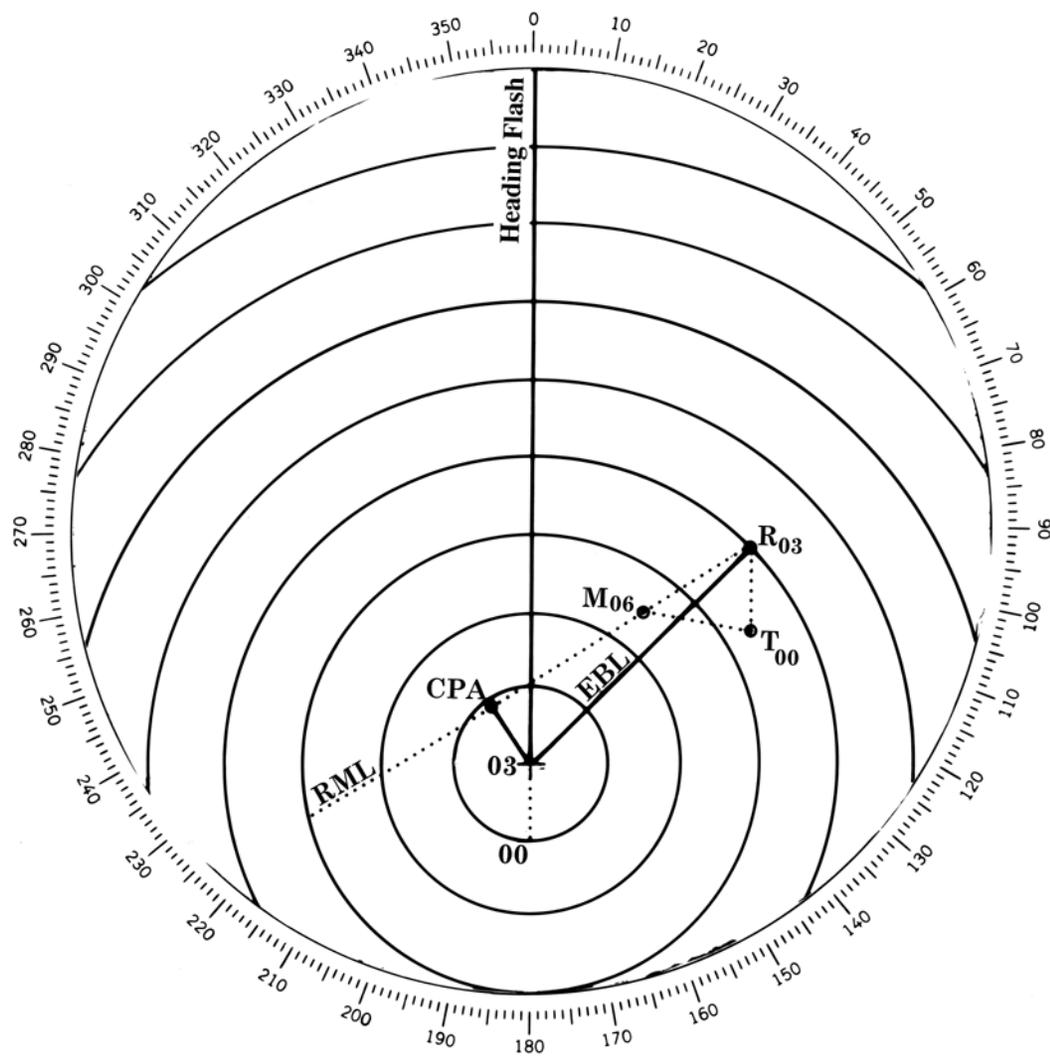


Own ship's course 000°
speed 20 knots

Contact's course 280°
speed 30 knots

Range-ring interval: 1 mile

Figure 3.48 - True motion display with electronic bearing line holding the bearing and range at which initially set.

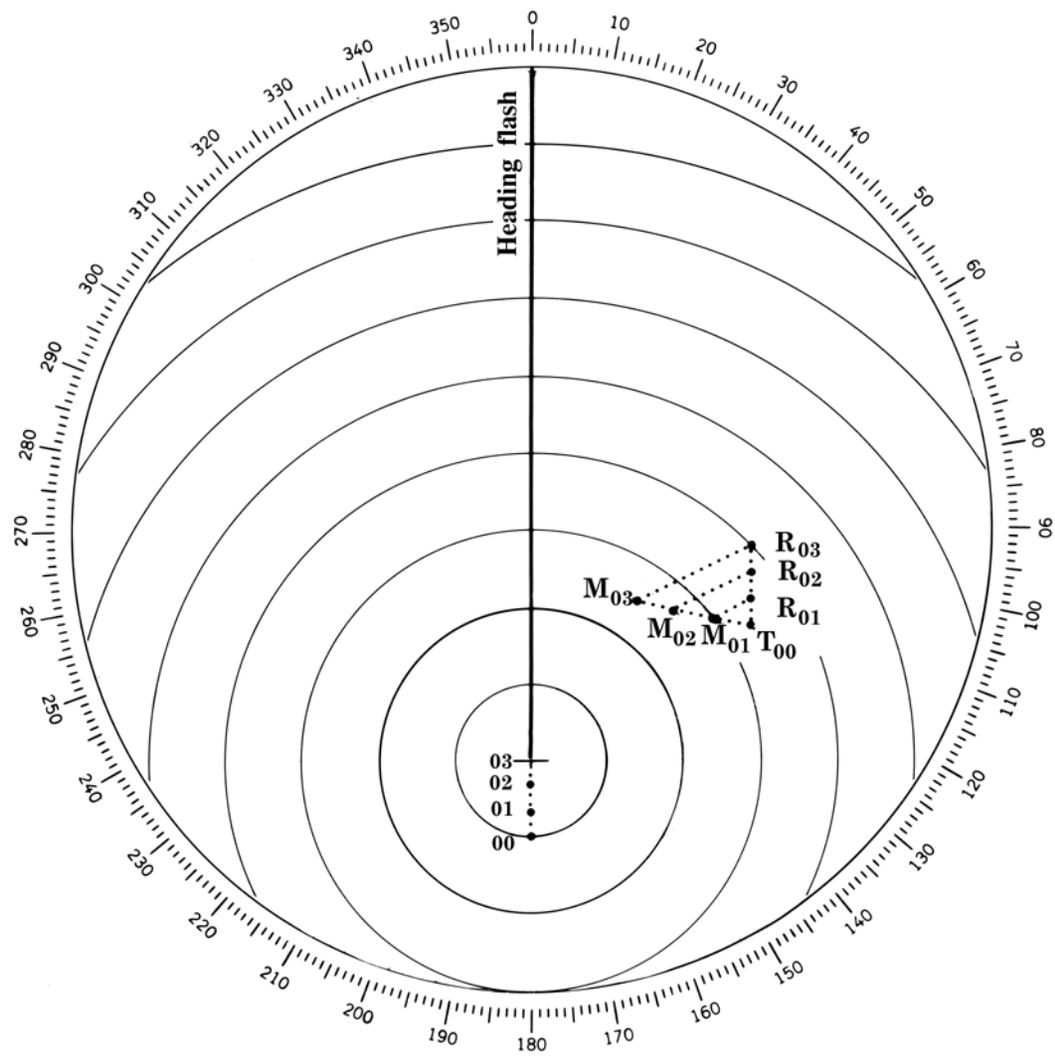


Own ship's course 000°
speed 20 knots

Contact's course 280°
speed 30 knots

Range-ring interval: 1 mile

Figure 3.49 - Solution for CPA on true motion display.



Own ship's course 000°
speed 20 knots

Contact's course 280°
speed 30 knots

Figure 3.50 - Construction of *R-T-M* triangle at any time.

SITUATION RECOGNITION

INTRODUCTION

The rules for Situation Recognition were developed by Mr. Max H. Carpenter and Captain Wayne M. Waldo, former members of the faculty for the Maritime Institute of Technology and Graduate Studies, Linthicum Heights, Maryland. The following information is printed from Section VII of the *Real Time Method of Radar Plotting*.

As your RTM plotting skills increase so will your ability to instantly recognize dangerous situations without a plot. This skill can be described as Situation Recognition, and makes use of everything you have learned and practiced thus far.

This ability to recognize a situation as you view it on radar will mark you as an exceptionally competent mariner.

In a risk of collision situation, the *true* or *compass* direction of relative movement must be changed. Simple rules for rapid prediction of the change in the compass direction of relative movement (DRM) of a radar contact resulting from a course or speed change by own ship can be invaluable, particularly in confusing multiple-contact situations.

The rules can be used only when using a *stabilized relative motion* display. Attempting to apply these rules using an unstabilized radar display could be very dangerous since a high degree of compass orientation is required to discover and avoid the risk of collision. Preferably, the radarscope should have high persistence.

Situation Recognition can be thought as a two-step procedure. The first is to ascertain the risk of collision as required by the Rules of the road. The

second is to recognize those actions you can take which will reduce the risk of collision, i.e. increase the passing distance

Step one; is relatively simple provided you obey the instruction given in the Steering and sailing Rules and ascertain the risk of collision, by “carefully watching the compass bearing of an approaching vessel. Therefore, your radar must give you the compass reference you need to recognize risk of collision. This means that the situation at a glance requires a gyro stabilized display. Unless your radar is so equipped that you can, at a glance, observe the compass bearing change of all approaching vessels you are seriously handicapped. There is no way you can, at a glance, determine the risk of collision by observing the relative bearings of approaching vessels. To repeat: there is only one method that is 100% reliable in determining risk of collision either visually or by radar, and that is the one given in the Steering and Sailing Rules. In this game of collision avoidance if you cannot satisfactorily answer the requirements of step one, it is impossible to evaluate the actions required in step two.

Step two; consists of deciding which of the four basic collision avoidance maneuvers will best increase the passing distance (turn left, turn right, speed up, slow down). This is relatively easy for you have been making these same decisions all your life. If while you are moving you visually observe an object coming towards you, you can very quickly decide how best to avoid a collision by either turning right or left, speeding up or slowing down. You do exactly the same thing using a radar to observe contacts coming towards the center of the scope.

RULES FOR SPEED CHANGE

The following rules provide predictions of how a contact's relative motion changes with a speed change by own ship. The predictions are valid irrespective of the position of the contact in range and bearing.

Reduced Speed

The relative plot moves up-the-scope when own ship reduces speed or stops.

Increased Speed

The relative plot moves down-the-scope when own ship increases speed.

Speed of Relative Motion (SRM)

The effectiveness of a turning maneuver depends, in part, upon the SRM of the radar target. A target whose SRM is high will show less change in relative motion than a similarly located contact with a low SRM.

Assume two contacts on collision courses approaching the observer's vessel at the same speed, with one contact 40° on the observer's port bow and the other 40° to starboard. A right turn will result in a small change in the DRM of the contact to starboard and a much larger change in the one to port. The difference is explained by the fact that the turn toward the starboard contact raised its SRM, making it more difficult to change. The port contact's SRM was reduced. As a result, the amount of DRM change was greater.

Thus, the effectiveness of a turn to avoid a contact is enhanced by turning away from the contact. This is illustrated in Figure 3.52.

SITUATION DISPLAYS

The series of illustrations which follow, shows various steps in evaluating the results of own ship's maneuvers using only the direction of relative motion as presented, and demonstrates the immediate readability of information sufficient to make risk of collision assessment and maneuver. These photographs were taken of a 16 inch stabilized north up relative motion radar, the range setting is 6 miles. Views A and B show the situation up to the decision time of 3 minutes. Views C thru J show the results of four simulator runs demonstrating each basic maneuver.

These illustrations show that it is possible for the maneuvering officer to

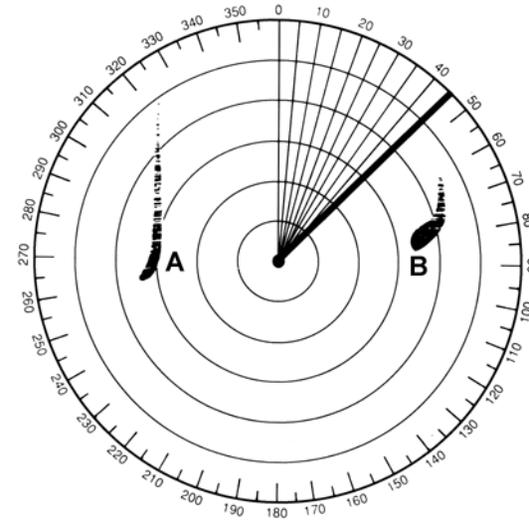


Figure 3.52 - Effects of a course change against targets with different speeds of relative motion.

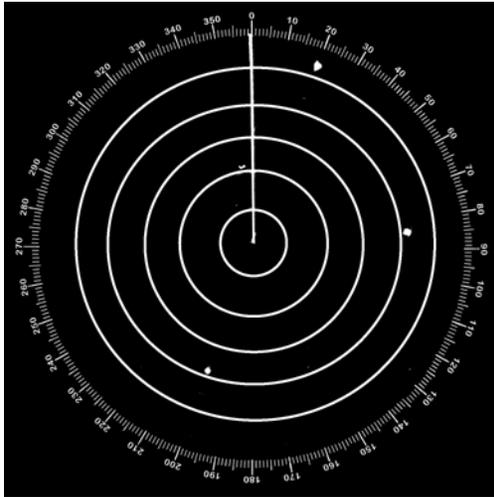
have instantaneous, readily available, at-a-glance information which will "hang in" when the going gets rough and when orientation seems to be the most threatened. This is important, for it is difficult to assess a maneuver by reading a list of numbers concerning the threat and then mentally trying to associate those numbers with what own ship is doing.

APPLICATION

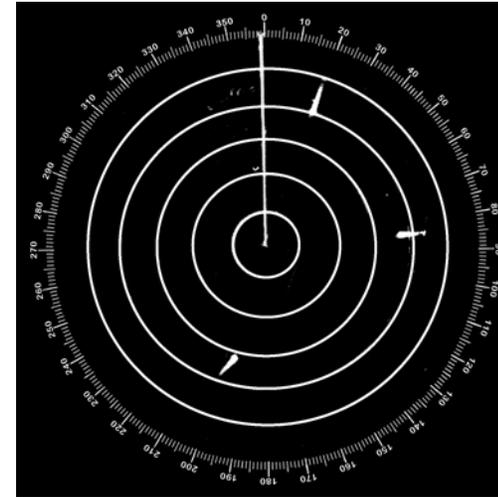
Figures 3.53 to 3.56 illustrate the use of the rules in evaluating the effects of evasive action by own ship.

When the contact is faster than own ship, the effect of own ship's evasive action on the compass direction of relative movement is generally less than it would be if own ship were the faster ship. Note that the contact is *always faster* than own ship in the up-the-scope and across-the-scope cases.

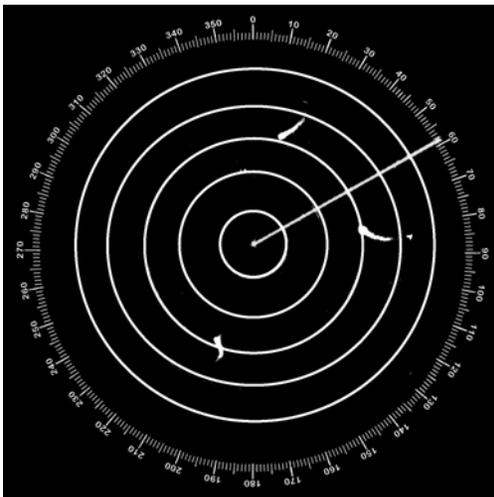
In making maneuvering decisions using the DRM technique, speed information on a ratio basis is adequate. The observer need only know whether the contact's speed is about one-half, three-fourths, or twice own ship's speed for example.



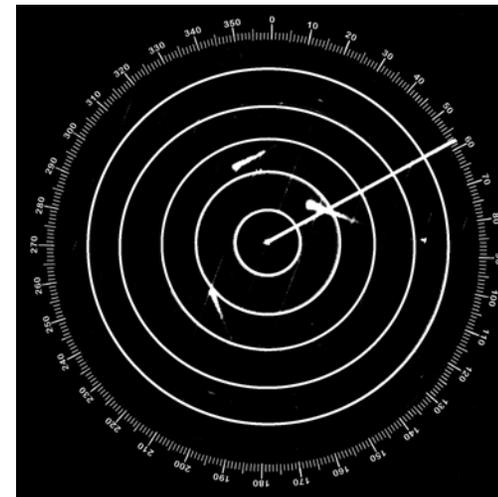
View A Upon switching from standby to on, we discover 3 contacts. No risk of collision is available therefore no maneuver decision can be made.



View B After the end of 3 minutes the direction of relative motion reveals that risk of collision exists with contacts on the starboard bow and beam. In other words the compass bearing is not changing on these two contacts.



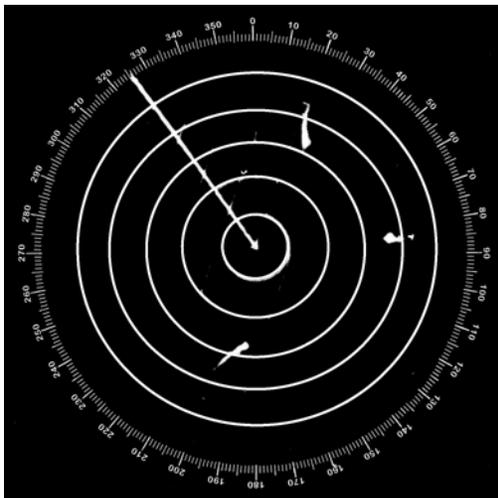
View C At the end of 5 minutes a decision to turn right 60° has resulted in a change in DRM of all contacts. The contact astern has changed his DRM from up to across category.



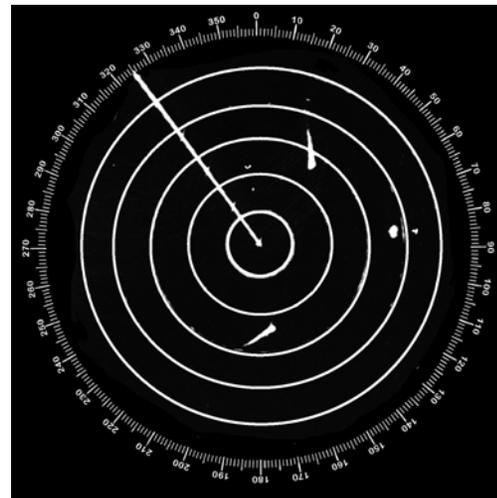
View D Approximately 10 minutes from the start the Master can begin coming back to base course expecting to achieve 1.5 mile CPA on all targets.

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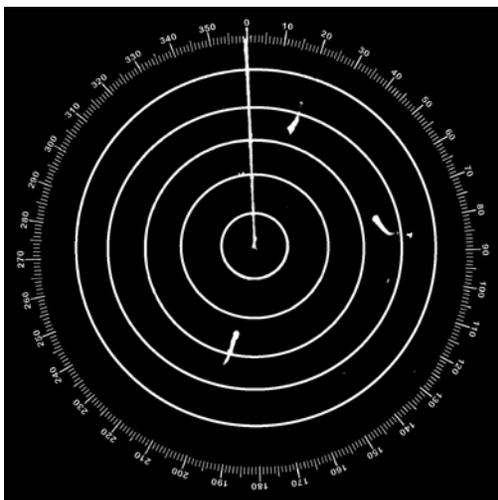
Figure 3.53 - Predicting effects of evasive action.



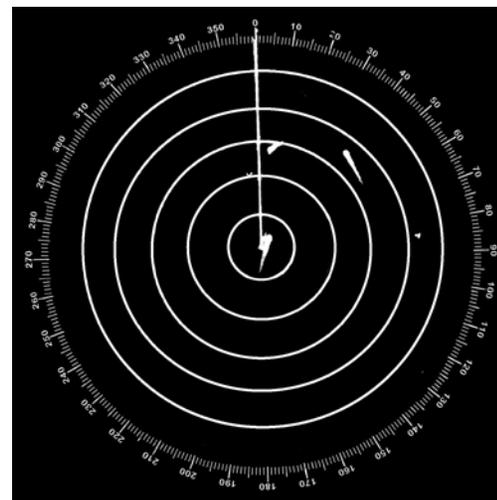
View E Same situation as Fig. 3 at five minutes, but with a 35 deg. left turn. Note “down” contact has moved to his left, “up” contact to his right.



View F The decision nine minutes from first observation for 35 deg. left projects a 1.5 mile CPA. Notice the beam contact has lost most of its relative motion, thus revealing his course and speed to be about the same as own ship's at this instant.



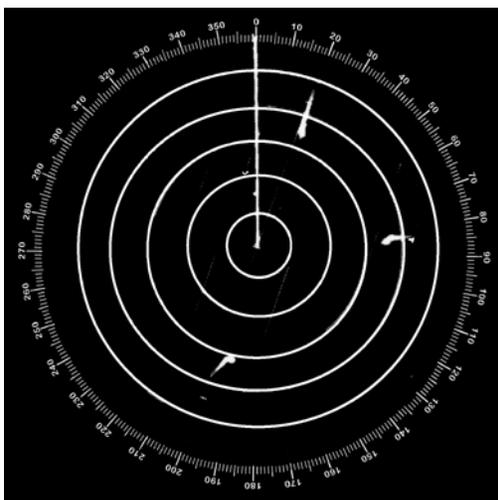
View G This is the original situation plus five minutes. The Master in this instance decided to stop. Note that all DRM is swinging forward.



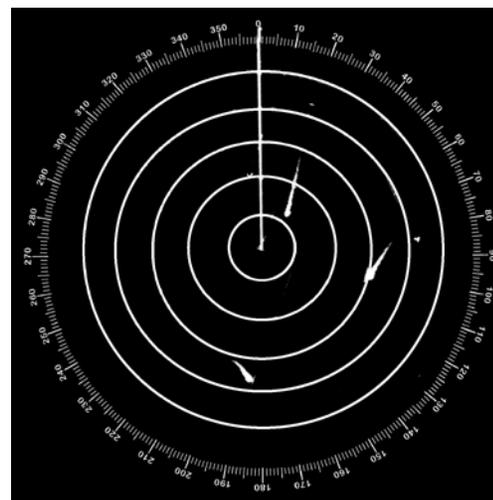
View H After 11 minutes, the action to stop has resulted in a close quarters situation.

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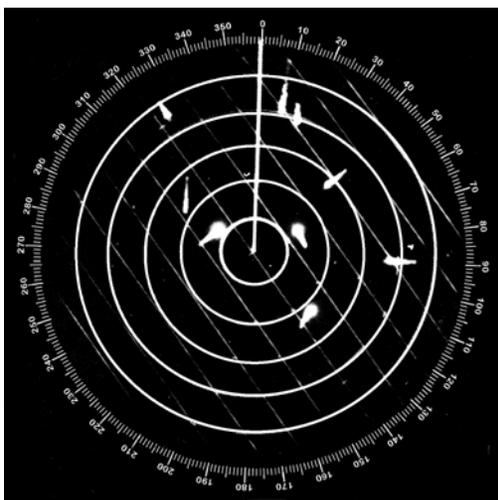
Figure 3.54 - Predicting effects of evasive action.



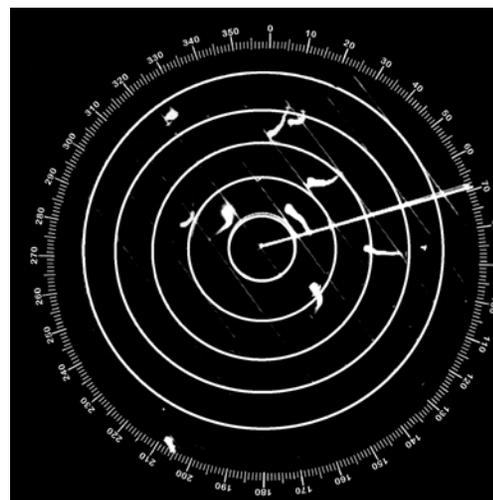
View I At five minutes the decision to increase speed from half to full ahead results in a swing of all DRM aft. It is apparent that vessel whose DRM is 195 deg. will pass close but clear.



View J After 10 minutes it is obvious that all contacts will pass clear, but contact whose DRM is 195° will clear by only one-half mile.



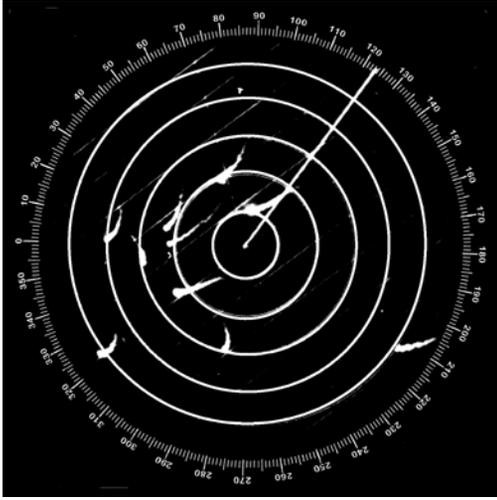
View K A high density situation.



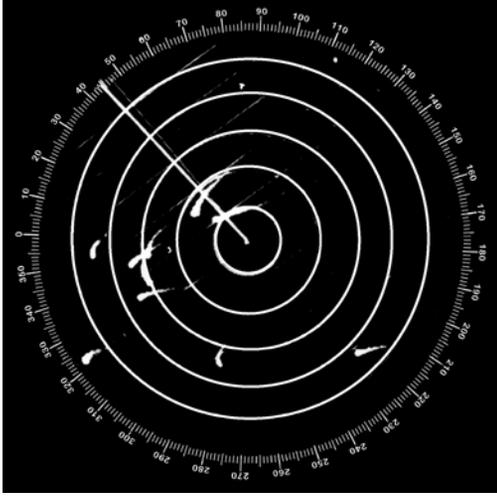
View L Trying for a 1-mile CPA in the high density situation illustrated in View K the conning officer comes to course 060°. After 2 minutes he notes that the contact bearing 125° will pass too close. Therefore, he starts to come to course 125°.

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Figure 3.55 - Predicting effects of evasive action.



View M The relative plots of all contacts are changing according to the rules.



View N After 6 minutes the conning officer can resume his original course.

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Figure 3.56 - Predicting effects of evasive action.

RULES FOR MANEUVERING

To maneuver using the information from “situation recognition” requires a technique whose effectiveness has been demonstrated in the radar laboratory and is currently being used at sea. This technique makes use of the “natural” ability we all have in avoiding collision with moving objects in daily life. This ability is, an understanding of relative motion. In this technique we use the Direction of Relative Motion (DRM) as the key to the whole thing.

In considering this key, let’s remember that any collision avoidance system requires, as a minimum, a stabilized radar which has the high persistence phosphor C.R.T. With this we have a display from which we can obtain the information on the DRM almost at a glance. With a few simple rules concerning this direction of relative motion, and a Deck Officer with maneuvering experience, we now have a competent marine collision avoidance system.

In viewing any radar scope, the direction in which the ship’s heading flasher is pointing can be described as “up the scope”. The reciprocal of it is a direction opposite to the heading flasher, or “down the scope”. A contact moving at right angles to the heading flasher anywhere on the scope would be described as “across the scope”.

The rules we use to show that DRM is the “key” are based solely on the relationship of DRM with reference to own ship’s heading flasher. These rules alert the deck officer to the expected effect on DRM as a result of any collision avoidance action, such as any course or speed change. We have three specific rules concerning course change, two specific rules concerning speed change, and two subordinate rules which apply to the technique described therein.

Rule number one: Any contact appearing on the scope, regardless of position in range and bearing whose direction of relative motion is up-the-scope, from a few degrees up, to parallel to the heading flasher, when own ship turns right, the direction of relative motion of the observed threat will turn to its left.

Rule number two: Any contact whose direction of relative motion is down-the-scope, that is, anywhere from a few degrees down, to parallel to

the heading flasher but in the opposite direction, when own ship turns right, the direction of relative motion will turn to its right. (Views A-D) This rule also applies in the case of a left turn as shown in (Views E and F).

Rule number three: Any contact whose DRM is across-the-scope is in “limbo”. Changing of own ship’s course left or right will have very little effect on the crossing contacts DRM until it’s category is changed to either a “down contact” or “up contact”, and then the contact will follow rules One or Two as stated previously (View F).

Rule number four: If own ship reduces speed or stops, all relative motion observed on your scope will swing forward or “up-the-scope”, no matter where they are. (View G).

Rule number five: Conversely, if own ship increases speed, all relative motion will swing aft, or down the scope. (View I).

The experienced mariner of course knows that any contact whose relative motion is up-the-scope is a faster ship. this fact also applies to contacts whose direction of relative motion is at right angles to the heading flasher as in rule three contacts.

Though specific speed is not available in using the DRM technique, the speed information is adequate for making decisions in maneuvering. The experienced officer usually handles speed on the basis of a ratio. Is the threat’s relative speed faster or slower than own ship’s speed?

Rule number six: If contact’s relative speed is high, the effect of own ship’s avoiding action is low.

Rule number seven: If contact’s relative speed is low, the effect of own ship’s avoiding action is high.

To state Rules 6 and 7 in another way, if the contact is faster than own ship, it is likely to be harder to maneuver against. If it is slower, then own ship essentially is in command of the situation.

